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Soil and Crop Interrelations of Various Nitrogenous Fertilizers

Windsor Lysimeter Series B

M. F. Morgan and H. G. M. Jacobson

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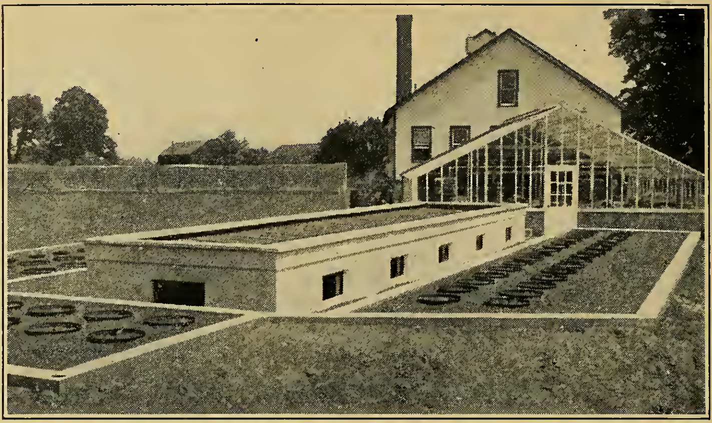

Lysimeters at Windsor Substation. Above, exterior view, taken in 1929. Below, interior view showing collecting chamber.

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Nitrogen as a fertilizer may be supplied from a greater variety of sources than any of the other nutrient elements. Inorganic salts furnish nitrogen as the nitrate, in combination with various bases, or as the ammonium radical in salts of various acids. Synthetic organic chemicals supply nitrogen as carbamide (urea) and as cyanamid. Natural organic materials of many sorts contain a sufficiently high amount of readily decomposable proteins to be useful in fertilizers. These include: various oil seed meals, such as cottonseed meal, linseed meal and castor pomace; packing house by-products, as tankage and dried blood; fish scrap; various animal manures.

Only one class of the above materials, the nitrates, supplies nitrogen in a form that is immediately and completely available to all plants. However, nitrates are susceptible to leaching from the moment they are applied to the soil. The nitrogen in ammonia compounds is at least partly available to plants in the form it is used, and the ammonia radical is not readily leached from the soil. However, ammonia is transformed in the soil to nitrates by biological nitrification, becoming more completely available as well as subject to losses by leaching. Urea and cyanamid quickly hydrolyze to ammonia when in contact with the soil and are subsequently nitrified. Proteins in natural organic materials are acted upon by organisms effecting their decay, to produce ammonia that may become changed to nitrates.

The various materials also differ with respect to their interactions with the active constituents of the soil. Some increase the supply of soil bases, as in the case of the nitrate salts. Others produce depletion of bases through combined crop removal and leaching, thus increasing the acidity of the soil, as instanced by the ammonia compounds and most organic materials. Such changes indirectly affect crop growth, and often materially alter the chemical make-up of the soil.

In spite of the above differences in the sources of nitrogen in fertilizers, it has become common practice in most cases to consider only the total amount of nitrogen supplied to the soil, irrespective of the form in which it is supplied. This view has appeared to be agronomically sound as evidenced by numerous fertilizer trials with field crops since the yield differences between various nitrogenous fertilizers supplying equal amounts of nitrogen were of insignificant magnitude. Such results were possibly affected by numerous compen-

sating factors. The lime content and absorptive capacity of the soil could mask the acid effects of the treatment. Early leaching of nitrates from soils supplied with nitrogen in this form tends to equalize the results with those from other materials giving slower and less complete liberation of available nitrogen.

During recent years, the differential effect of nitrogenous fertilizers with respect to the acidity of the soil have become generally recognized. Meyer (13) in 1881, and Lawes Gilbert and Warrington (10) in 1882 were investigators who early pointed out such differences with respect to nitrate and ammonia salts. It began to receive consideration in this country with the work of Wheeler and Towar (21) in 1893. Later, other fertilizers were studied and various efforts were made to give a quantitative expression to the effects of nitrogenous fertilizers upon the base status of the soil, culminating in the scheme proposed by Pierre (16) for expressing the equivalent acidity and basicity of fertilizers. The literature in this field has been comprehensively revised in an early publication by the senior author (14).

The qualitative differences in fertilizer nitrogen have been most generally recognized where the value of the crop is largely dependent upon the quality of the marketed product, rather than upon the total yield. This has been especially true in the case of cigar leaf tobacco, as grown in the Connecticut Valley. The effects of various nitrogenous fertilizers upon the production and quality of such tobacco were studied to some extent in early experiments (1892-'96) at this Station by Jenkins (8) and have been constantly under investigation by the Tobacco Substation since its establishment in 1922. Recent contributions in this field are presented in Bulletin 444 of this Station, (3).

Many studies relative to the amounts of nitrogen liberated to the crop from various fertilizer materials are extant in the literature. This Station gave early attention to the subject, conducting pot experiments such as those reported by Johnson, Jenkins and Britton (9). Those were followed by carefully conducted cylinder experiments under outdoor conditions at the New Jersey and Rhode Island Stations. The former were reported by Lipman and Blair (11) for the 1898-1912 period, and by Lipman, Blair and Prince (12) for the 1913-27 period and, more recently, by Prince and others (18). Hartwell, Wheeler and Pember (7) summarized the early Rhode Island work. Many field fertilizer plots with various crops have been conducted in numerous states. Such trials have yielded valuable, practical agronomic information. However, they have failed to give a complete picture of the complex inter-relationships involved in rates and total amounts of nitrate production, crop intake at different stages of growth, losses through the leaching of soluble material from the soil by gravitational soil water after heavy rains and snow meltings, acidic and basic effects and other soil changes resulting from the continued use of a given fertilizer material.

Under humid conditions, where gravitational water passes through the soil at frequent intervals, the losses of nitrogen and sev-

eral other soil constituents may equal or exceed crop utilization. Hence, a fundamental study of the effects of fertilizer upon both the crop and the soil can be conducted to best advantage under lysimeter conditions, providing for the measurement and chemical analysis of the leachate as well as of the crop. Changes that occur in the soil as a result of treatment can thus be evaluated to the fullest extent.

The present report deals with such a study of fifteen nitrogenous materials, applied to the soils in lysimeter tanks as components of complete fertilizers for tobacco, supplying nutrients in amounts such as commonly used for the crop in the Connecticut Valley. This experiment, designated as Windsor Lysimeter Series "B," begun in 1929, was conducted for ten years under differential nitrogen treatment and, for an additional year without nitrogen, to measure residual effects.

PLAN OF INVESTIGATION

The physical equipment for conducting lysimeter experiments was described in detail in an earlier publication (14). The lysimeters are located at the Tobacco Substation at Windsor. The installation is as shown in the frontispiece.The tanks of Series "B" occupy the middle row on the courts surrounding the collecting chamber. These tanks are 20 inches in diameter and 20 inches in depth, exclusive of the tapering bottom filled with quartz sand. Successive fillings of mixed, carefully packed field soil, representing substratum (C) at 14½ to 18-inch depths, subsoil (B) from 7 to 14½-inch depths and surface soil (A) at from 0 to 7-inch depths, were placed in the tanks. The soil surface in the tanks was approximately 2 inches below the rims, after settling for a few months.

The soil used in this experiment is of the Merrimac sandy loam type, from a plot used for several years for tobacco, with oat cover crops. It was taken from the same location as the surface soil used in tanks 25 to 34 in Series "A," reported in Bulletins 384 and 429 of this Station.

The amounts of soil used in the tanks, on the dry weight basis, for the various depths, were as follows:

	Thickness inches	Lbs. per tank	Equivalent lbs. per acre	
			Total soil	2 mm. soil
Surface soil (A)	7.	116.05	2,321,000	2,300,000
Subsoil (B)	7.5	144.00	2,880,000	2,800,000
Substratum (C)	3.5	74.75	1,475,000	1,400,000

Pertinent physical and chemical measurements of the original soil, based on material passing a 2 millimeter screen, are given in Table 1.

The fertilizer treatments were applied in dry form, mixed thoroughly with the upper 2 or 3 inches of soil, on May 26 of each year

of the experiment. Each treatment was in duplicate on opposite sides of the lysimeter.

Table 1. Physical and Chemical Characteristics of Soil Horizons Used in Lysimeter Series B, 1929-'40.

	Surface soil A	Subsoil B	Substratum C
Mechanical Analysis		(In percentages)	
Sand	74.2	76.5	78.6
Silt	19.0	18.9	18.6
Clay (.002 mm.)	6.8	4.6	1.8
Total water holding capacity	31.7	31.5	29.7
Moisture Equivalent	9.6	7.0	6.1
Organic matter	2.174	0.733	0.483
Nitrogen total	.0620	.0225	.0130
Phosphorus total	.1313	.0350	.0286
Potassium total	1.430	1.372	1.222
Calcium total	.731	.936	.769
Magnesium total	.311	.310	.268
Exchangeable bases		(Mgm. — equivalents per 100 gms.)	
Calcium	1.33	.55	.45
Magnesium	.38	.36	.25
Potassium	.43	.41	.28
Sodium	.03	.03	.02
Manganese	.02	——	——
Exchangeable hydrogen	3.15	1.40	1.20
Base exchange capacity			
by summation	5.34	2.75	2.20
determined	5.20	2.70	1.70
average	5.27	2.72	1.95
Relative base saturation %	41.6	49.6	51.3
Soil reaction—pH	5.17	5.51	5.48

All tanks received phosphoric acid (P_2O_5) at the rate of 100 pounds, potash (K_2O) at the rate of 200 pounds and magnesia (MgO) at the rate of 50 pounds (30 pounds for the first two years) per acre per year, except in cases where the quantities in the materials used to supply nitrogen were in excess of these amounts. These were added as precipitated bones, carbonate and sulfate of potash, carbonate of magnesia or as constituents of the nitrogenous material. Each of the nitrogen treatments supplied 200 pounds of nitrogen per acre annually. No nitrogen was applied in 1939.

One plant of "shade" tobacco (4 R strain) was set in each tank, soon after applying the fertilizer. Cultural practices in growing the crop closely approximated those for field-grown tobacco. Except in two seasons of unusually dry weather when small amounts of irrigation water were added, the crop was dependent upon natural rainfall. The tobacco plants, cut down to ground level at maturity, were dried, weighed and pulverized for subsequent chemical analysis.

The tobacco crop of 1929 was completely cut to pieces by a severe

hailstorm on August 31. It was impracticable to remove the fragments accurately, hence they were turned under by spading.

At the conclusion of each period of leaching, the quantities of water that had drained into the collecting vessels were weighed and sampled. Nitrate nitrogen was determined as quickly as possible on each lot of leachate.[1] Aliquot samples from successive periods of leaching were placed in glass bottles containing toluene (5 milliliters per gallon of leachate) to prevent further biologic action. The weighted composites thus obtained were analyzed for various soluble constituents by six-month periods, ending in May 25 and November 25 of each year.

The total quantities of the various elements added to the tanks during the 11 years by the fertilizer treatments and by atmospheric precipitation are shown in Table 2.

The amounts contributed by atmospheric precipitation are computed from analyses of water collected in circular pans located in the east and west lysimeter courts. These pans are 20 inches in diameter, 4 inches deep, with funnel bottoms and underground drainage tubes leading to collecting vessels. These rain gauge tanks were installed in 1931. Results for the nine years were computed to 11 years.

The materials used in these trials were lots purchased for use on the fertilizer plots conducted by the Tobacco Research Department at Windsor. The details of the chemical composition of various lots of each ingredient in the fertilizer mixture are omitted. However, the data in Table 2 are based on exact analyses conducted at this Station, chiefly by the Department of Analytical Chemistry.[2]

The cow manure used from 1932 to 1938 represented fresh cow manure, obtained from a combination dairy-tobacco farm in the spring of 1934, air dried and stored in a tight container for use in subsequent years. Analyses for nitrogen, phosphoric acid and potash were obtained at the beginning. Unfortunately, calcium and magnesium were not determined on this manure until the close of the experiment. It was then discovered that the dry manure contained 4.8 percent of calcium and 0.83 percent of magnesium, indicating that limestone had been added to the manure. It was estimated that the extra calcium and magnesium content represented approximately 50 pounds of limestone in one ton of fresh manure. The farmer confirmed this, having added some limestone in the gutters of his stable as an absorbent. The manure used during the first three years was fresh cow manure, of normal chemical analysis.

The methods for analyses of leachates employed in this study are substantially as indicated in Bulletin 384 (14), published by this Station.

[1] These nitrate measurements and other details of the work at Windsor were conducted by O. E. Street, formerly Assistant Plant Physiologist at the Tobacco Substation.

[2] The cooperation of Dr. E. M. Bailey, Station Chemist, has been of great assistance in the conduct of this experiment, through analyses of fertilizer materials and of the crops.

TABLE 2. QUANTITIES OF VARIOUS ELEMENTS ADDED BY TREATMENTS AND RAINFALL, LYSIMETER SERIES B, 11-YEAR PERIOD, 1929-'40.
(Pounds per acre.)

Tank Numbers	Nitrogen sources (used for ten yrs.)	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)	Sodium (Na)	Sulfur (S)	Chlorine (Cl)
101-102	Nitrate of soda	2042	481	1934	355	911	3003	655	211
103-104	Nitrate of potash	2042	481	5876	355	911	200	391	304
105-106	Nitrate of lime	2042	481	1934	355	3436	153	655	244
107-108	Sulfate of ammonia	2042	481	1934	355	911	179	2941	278
109-110	Ammophos	2042	3005	1934	355	558	176	1283	273
111-112	Urea	2042	481	1934	355	911	150	655	240
113-114	Calurea	2042	481	1934	355	1483	154	655	245
115-116	Cyanamid	2042	481	1934	355	4761	138	690	224
117-118	Cottonseed meal	2042	481	1934	355	461	148	567	238
119-120	Castor pomace	2042	481	1934	363	677	175	562	272
121-122	Linseed meal	2042	481	1934	363	627	165	577	259
123-124	Fish meal	2042	973	1934	355	1669	203	696	308
125-126	Hoof and horn meal-3 yrs. No nitrogen-8 yrs.	642	500	1934	355	1091	133	665	218
127-128	Dried blood	2042	481	1934	355	588	228	701	327
129-130	Tankage	2042	700	1934	355	1519	279	675	367
131-132	Cow manure (with limestone)	2042	573	1751	878	4236	235	655	336
133-134	No nitrogen	42	481	1934	355	911	123	655	205
——	Rainfall contributions	42	0	107	54	208	119	255	200

Samples of soil from each of the three horizons have been subjected to laboratory study. These comprised the original soil, collected at the time of filling the tanks, and the soils in the various tanks when removed at the conclusion of the eleven-year period. Analyses included: total nitrogen, organic carbon, total phosphorus, available phosphorus by the method of Truog (20), total potassium, base exchange capacity and exchangeable hydrogen by the method of Pierre and Scarseth (17), determination of various exchangeable bases by the methods of Schollenberger and Dreibelbis (19), moisture equivalent by the methods of Briggs and McLane (6), mechanical

TABLE 3. ATMOSPHERIC PRECIPITATION AND DRAINAGE DATA FROM CROPPED TANKS, WINDSOR LYSIMETER SERIES B, 1929-'40.
(In inches.)

	1929-'30	1930-'31	1931-'32	1932-'33	1933-'34	1934-'35	1935-'36	1936-'37	1937-'38	1938-'39	1939-'40	Av. 11 yrs.	Hfd. Av. 78 yrs.
June-pptn	1.67[1]	3.73	4.74	2.86	1.96	3.47	5.53	2.75	5.63	7.00	4.37	3.97	3.08
leached	0.38	1.52	3.90	—	—	1.24	0.72	—	1.54	2.02	—	1.03	
July-pptn	0.98	2.63	2.90[2]	3.99	2.43	3.20	4.30	2.45	4.40	8.54	2.56	3.49	4.37
leached	—	—	—	—	—	—	—	—	0.06	4.49	—	0.41	
Aug.-pptn	4.87	2.33	3.87	5.72	3.42	3.45	2.05[3]	4.35	6.81	2.11	5.62	4.05	4.92
leached	0.60	—	—	—	—	—	—	—	—	—	—	0.01	
Sept. pptn	2.12	1.56	0.98	3.53	4.85	8.63	4.78	3.86	4.33	12.63	2.22	4.50	3.49
leached	—	—	—	0.65	2.01	3.43	0.54	1.17	2.74	8.51	0.42	1.77	
Oct. pptn	3.42	2.36	1.70	4.18	1.70	2.11	0.43	3.92	4.62	1.83	2.20	2.59	3.50
leached	0.54	—	—	1.90	—	1.84	—	2.14	2.08	—	—	0.77	
Nov. pptn	2.35	2.71	0.78	5.54	0.58	2.17	4.13	1.14	6.02	3.95	2.81	2.93	3.55
leached	1.60	1.44	—	5.27	—	1.09	1.24	0.21	4.98	—	2.61	1.68	
Dec. pptn	3.85	2.43	3.00	1.88	3.44	2.75	0.82	5.65	1.67	3.65	3.02	2.92	3.97
leached	0.01	—	1.26	—	—	—	—	2.73	—	4.00	—	0.72	
Jan. pptn	2.51	3.46	4.59	1.73	4.11	4.02	5.80	5.58	4.39	2.79	0.17	3.56	3.94
leached	1.46	—	3.62	0.91	—	1.45	—	6.04	—	—	—	1.23	
Feb. pptn	2.05	1.65	2.17	3.89	3.98	2.74	2.21	1.69	1.85	2.17	1.91	2.33	3.83
leached	1.28	—	—	1.59	—	—	—	—	—	—	—	0.26	
Mar. pptn	3.64	4.26	4.89	5.56	3.84	1.49	5.98	3.06	1.49	4.59	4.97	3.98	3.90
leached	2.57	3.06	3.46	6.50	2.54	2.42	5.53	3.89	0.71	5.37	2.30	3.49	
Apr. pptn	1.54	2.46	1.53	4.13	5.35	1.28	3.38	3.82	4.44	4.39	5.62	3.45	3.36
leached	—	0.97	1.91	3.55	4.57	—	2.83	—	—	1.96	4.35	1.76	
May-pptn	4.48	6.52	1.65	1.58	3.85	1.40	2.38	4.09	4.21	0.95	4.08	3.20	3.60
leached	—	1.41	—	—	—	—	—	1.34	2.73	—	—	0.50	
Lysimeter year pptn	33.48	36.10	32.80	44.59	39.51	36.71	41.79	42.36	49.90	54.60	38.83	40.97	44.88
leached	7.90	8.40	13.43	20.37	9.12	11.47	10.86	17.52	14.84	26.35	9.68	13.63	

[1] Rainfall during May, 1929—4.79 inches.
[2] Includes irrigation water—1.06 inches.
[3] Includes irrigation water—0.25 inches.

analysis by the method of Bouyoucos, (5). Unless otherwise indicated, A. O. A. C. methods have been employed.

Measurements of pH for the surface soils in the tanks were made in April or November, during the course of the experiment and upon the final samples. The glass electrode method was used except during the first four years.

PRECIPITATION AND OTHER WEATHER CONDITIONS DURING THE EXPERIMENT

The time of installation of these lysimeters was coincident with the beginning of a dry cycle. Annual rainfall was more than 5 inches below normal (44.8 inches) for each lysimeter year until 1935-'36, except for 1932-'33. The next four years were approximately normal or above normal in total rainfall, culminating in the extremely wet year of 1938-'39 (the year of the great hurricane of September 21, 1938). The final year, 1939-'40, was moderately dry.

The average amount of drainage water collected during each month, for the cropped tanks of this series, in relation to precipitation, is shown in Table 3.

The vagaries of the weather that had marked effects upon the distribution and amounts of leaching from the tanks is briefly reviewed in the following paragraphs:

1929-'30: After a wet May, early June rains produced some leaching. Dry, hot weather prevailed until the heavy storm and hail of the afternoon of July 31 (collected in drainage water on August 1). Further August rains caused leaching. The fall was cool and moderately dry. Snow and rain on frozen ground in December caused no leaching, but mild weather in the other winter months permitted leaching after thaws. The spring months, after the final thaw in March, were too dry to cause leaching.

1930-'31: A storm period in June produced leaching. From then until November dry weather prevailed. Cold weather and light precipitation prevented leaching until the March thaw. April showers and heavy rains in May caused further leaching.

1931-'32: Storms in June, after a wet May, caused unusual leaching. The summer and fall were dry, except for August, hence no further leaching was collected until December. Mild temperatures and heavy rains in January caused much leaching. Following a wet winter, the March thaw leaching was unusually heavy. Early April rains on wet soil caused further drainage through the soil. The spring then became unusually dry.

1932-'33: The accumulated moisture deficit in the soil caused by persistent dry weather from April until late July permitted no leaching in August, even under a heavy rainfall in that month. A wet fall caused much leaching. By November the soil was so soaked with

water that practically the entire rainfall leached during that month. A dry, cold December prevented leaching. Mild weather during the late winter, followed by unusually heavy early spring rains, caused much leaching. Dry weather prevailed after mid-April.

1933-'34: Generally dry weather with well distributed showers persisted until heavy September storms caused leaching. The fall was otherwise unusually dry, leaving a moisture deficit in the soil at the time of freezing. Unusually cold winter weather prevented leaching until the March thaw. A wet April caused further drainage from the soil.

1934-'35: Following a normal rainfall during the previous month, rains in June produced leaching. A hot summer with well distributed moderate precipitation did not permit leaching. Very heavy September storms caused much leaching. During a cool fall light rains on damp soil gave more leaching than usual. After the onset of winter, a heavy rain and thaw in January was the only occasion for leaching until the March thaw. The spring was unusually dry.

1935-'36: Fairly abundant rainfall in June and July caused leaching only in the former month. Following a warm, dry August, two heavy rains in September produced but little drainage water. Very dry weather ensued until near the end of November, when two storms produced considerable leaching. A dry December and frozen ground during the rest of the winter prevented leaching until March downpours thawed the ground. Frequent showers in April caused further movement of water down through the soil. May was moderately dry.

1936-'37: June and July brought occasional light rains and warm weather. In August, plentiful precipitation again failed to produce leaching. Normal rainfall in the two following months leached the soil to some extent. Unusually wet, mild weather during early winter caused severe leaching. Following a cold, dry February, the March rains thawed the ground to yield further drainage water. Following normal rainfall in April, heavy May showers produced leaching.

1937-'38: Abundant June rains, after a moist spring, caused much leaching. In spite of frequent showers through July, a heavy rain near the end of the month barely saturated the soil. Even with this advantage, two heavy storms in August failed to leach the soil. September, with practically normal rainfall, showed much leaching. A wet fall caused an unusual volume of drainage water. A generally dry, cold winter and an unusually light March rainfall yielded a minimum of leaching for the "spring thaw" period. After frequent rains in April and May had further saturated the soil, more leaching than usual occurred during the latter month.

1938-'39: Very heavy June rains caused leaching on three occasions. A week of almost continuous rain, from July 19 to 24, pro-

duced exceptionally severe summer leaching. After a dry August and early September, several days of rainy weather, from September 17 to 21, culminated in the great hurricane. An estimated 4 inches of water, that should normally have been leached through the soil, overflowed the rims of the tanks, while the outlet tables were closed to prevent overflow of the collecting vessels. (This correction has been applied to the data indicated in Table 3.) After several weeks of dry weather, rains in late November produced no leaching, but left the soil in readiness for the passage of drainage water during early December storms. No further leaching occurred during the winter period. The spring thaw and heavy March and April rains caused much leaching. An unusually dry May ensued.

1939-'40: Frequent light rains during June caused no leaching. After a fairly dry July, heavy rains in August failed to fully saturate the soil. Most of the low September rainfall, concentrated in one storm, caused slight leaching. November precipitation, all in two rains early in the month, caused a high proportion of leaching. Dry weather and frozen soil throughout the winter yielded no leaching. Very little drainage water resulted from the spring thaw. A wet April caused much leaching. May rains occurring near the end of the month, after the tanks of Series "B" were discontinued, caused no leaching from soils in the tanks of other series in progress at the time.

General Conditions Affecting Leaching

Drainage water is produced when the precipitation exceeds the current moisture deficit of the soil resulting from evaporation and transpiration. During the summer, evaporation is at a maximum. Under cropped conditions the evaporation is checked by shading by the crop, but is more than offset by transpiration of moisture from the leaves. After harvest, evaporation losses diminish as temperatures become lower. During the winter precipitation accumulating on the soil surface as snow is evaported to a considerable degree. Soil freezing causes the accumulation of water in and on the soil in excess of saturation. Spring months bring increased evaporation, frequently accentuated by drying winds.

During the summer leaching is caused only by heavy rains, usually in excess of one inch or more of precipitation in a few hours. After several days of dry weather, more rain must fall in order to produce leaching than when the soil is already moist from frequent showers. After the soil is saturated, additional rainfall produces leaching almost at once.

August is the month when leaching is least apt to occur. This is logical since, at this time of year, the moisture deficit of the soil is most rapidly produced by evaporation and transpiration. July ranks next to August as a month of low leaching risks. However, heavy rainfall during June is the chief factor in causing leaching during the growing season, for the tobacco crop. Spring crops, fertilized earlier,

may often be affected by leaching during April, or in May, in years when a wet May follows a wet April.

Leaching during the fall months may be expected, except in unusually dry seasons. In winter, water may drain from the soil during mild periods resulting in thaws. This has happened most often in January. Otherwise, the soil is frozen to a depth sufficient to prevent leaching during the cold months.

March invariably causes some drainage water to pass through the soil. On the average, leaching is at a maximum during the early spring period. However, as will be shown later, the losses of soluble constituents from the soil by leaching at this time are less than those caused by earlier leachings.

The relationships between rainfall, leaching and losses of moisture from the soil by evaporation and transpiration during various periods of the year are summarized in Table 4. Since the March leaching represents much water accumulating in or on the soil during the preceding months, it is included in the winter period.

Table 4. Summary of Evaporation-Transpiration Losses by Seasonal Periods, Based on Average Data Windsor Lysimeter Series B, 1929-'40.

	Excess of precipitation over leaching	
	Period (inches)	Av. per day (inches)
Winter months		
Dec., Jan., Feb., Mar.	7.09	.059
Spring months		
April, May	4.39	.072
Summer months		
June, July, August	10.06	.109
Fall months		
Sept., Oct., Nov.	6.09	.069

These data are in general agreement with those reported for Lysimeter Series "A" in Bulletin **429.** (15). However, the latter represented surface soil only, under uncropped conditions.

Data from Tanks 125-126, uncropped from 1932 to 1940, provide some basis for comparing evaporation losses with those resulting from both evaporation and transpiration under tobacco cropping during a portion of the year. The average yearly increase in leaching on the uncropped tanks for seven years, excluding the hurricane year 1938-'39, has been 1.62 inches. With an average dry weight production of 3,420 pounds of tobacco per acre for the seven years of the comparison, this represents a water requirement of 1,075 pounds, per pound of dry weight, a fairly reasonable value under the conditions of this experiment.

It should be borne in mind that the rims of the tanks prevented run-off that might otherwise occur during heavy rains and during periods of snow melting with frozen soil underneath. When all of the precipitation must either evaporate or leach, drainage through

the soil is somewhat greater than when some of the water flows over the soil to surface drainage outlets. However, the difference is probably not great as compared with a level tobacco field of sandy soil, with a high infiltration rate. Even during periods of snow melting, there is little run-off under such conditions, although water accumulates in slight irregularities of the land surface, thus giving more than normal leaching after the ground thaws in such areas.

For level land, such as the Merrimac sandy loam most commonly used for tobacco in the Connecticut Valley, the run-off may be conservatively estimated at 10 percent of the total precipitation. Thus with a mean annual precipitation of 44.88 inches, under field conditions the leaching should be substantially the same as obtained under a precipitation averaging almost 10 percent less than normal, as in this experiment.

There have been no consistent differences between the amounts of leaching on the various cropped tanks. The "no nitrogen" treatment, producing approximately one-half the dry weight of tobacco obtained from nitrogen treatments, leached 0.53 inch more on the average (excluding the hurricane year). However, the variations from year to year and on replicate tanks prevented any statistically significant interpretations.

Leachings were slightly greater on the replicates on the west side of the collecting chamber, during the summer and fall seasons. However, this was compensated by somewhat more leaching on the east side at other times. This is due to the sheltering effect caused by the projection of the walls of the collecting chamber above the level of the tops of the tanks, thus serving as a windbreak. Summer storms blow most frequently from the southwest while winter blizzards, as a rule, ride on a northeast wind, in this locality.

NITROGEN AVAILABILITY FROM VARIOUS MATERIALS IN RELATION TO CROP REMOVAL AND RATE OF LEACHING

Since the 1929 tobacco crop was not harvested on account of hail damage, and the 1939 crop was grown without nitrogen treatment as a measure of residual effects, complete data for crop and leaching in years of nitrogen treatment are available only for the nine-year period of May 26, 1930, to May 25, 1939, inclusive.

The crops on the sulfate of ammonia treatments were generally poor, apparently due to the harmful effects of the excessive acidity resulting from this treatment. Crops on the cow manure treatment were unsatisfactory, due to insufficient available nitrogen from this treatment. The "no nitrogen" crop was small, as would be expected. Otherwise, it is questionable if the yield variations are of any significance. Occasional instances of poor plants, due to accident or injury, on one of the replicates, tended to cause yield variation.

The average composition and yield of tobacco, based on separate analyses of the tobacco plant in each replicate for each of the nine

years is shown in Table 5. Variations occurred from year to year. In some seasons yields were generally higher or lower than others, due chiefly to moisture conditions in the soil. However, the same general picture was shown throughout the experiment. These data will be considered in detail in subsequent discussions.

The nitrogen removed by the crop was in most instances in close relationship to the total nitrogen recovery in both crop and leaching. Approximately one-half of the total available nitrogen was to be found in the "above ground" portion of the crop as harvested. The low utilization in case of sulfate of ammonia is due to the harmful effect of the treatment. The amounts of available nitrogen from the nitrate materials were apparently too great for effective use. This is reflected in the higher percentages of nitrogen in the crop under such conditions.

The data for nitrate leaching have been tabulated by seasonal periods, so that the rate of leaching in relation to total nitrogen availability may be indicated. Table 6 includes a break-down of nitrogen recovery to show crop removal, leaching nitrates by periods, and ammonia nitrogen leaching.

TABLE 5. AVERAGE COMPOSITION AND YIELD OF TOBACCO WINDSOR LYSIMETER SERIES B, 1930-'39.

Treatment	Percent of dry weight									Average dry weight of crop[1] (Lbs. per A.)
	K	Na	Ca	Mg	Mn	N	S	P	Cl	
Nitrate of soda	2.74	.605	1.02	.399	.0059	2.78	.149	.228	.238	3255
Nitrate of potash	4.12	.168	.82	.375	.0070	2.54	.121	.180	.338	3626
Nitrate of lime	2.54	.067	1.69	.354	.0089	2.52	.157	.200	.258	3557
Sulfate of ammonia	2.61	.088	1.02	.368	.0746	3.11	.564	.272	.344	1969
Ammophos	2.24	.052	.85	.434	.0874	2.91	.317	.396	.322	2810
Urea	2.55	.071	1.25	.421	.0481	2.47	.179	.206	.292	3415
Calurea	2.59	.058	1.39	.401	.0360	2.55	.181	.206	.296	3532
Cyanamid	2.65	.063	1.49	.270	.0092	2.47	.221	.185	.290	3327
Cottonseed meal	2.44	.061	.92	.452	.0352	2.10	.204	.187	.262	3543
Castor pomace	2.36	.061	1.07	.375	.0397	2.13	.175	.181	.356	3385
Linseed meal	2.44	.065	1.02	.399	.0378	2.12	.199	.194	.276	3471
Fish meal	2.29	.063	1.27	.352	.0342	2.06	.202	.206	.372	3827
Dried blood	2.25	.065	1.07	.374	.0625	2.11	.184	.159	.398	3653
Tankage	2.41	.067	1.26	.366	.0312	2.08	.191	.209	.393	3983
Manure	2.16	.065	1.00	.392	.0047	1.43	.203	.226	.396	3314
No nitrogen	2.23	.077	.81	.307	.0076	1.17	.306	.259	.355	1602

[1] Including stalks.

Nitrate leachings were greatest from the nitrate materials during the growing season, as would be expected. However, under the conditions of this experiment, there still remained a sufficient amount of available nitrogen in the root zone to supply the crop with more nitrogen than was obtainable from any of the other treatments except in 1938. In that season the severe leaching of the soil depleted the available nitrogen from the soils of all tanks to such a marked degree that there was no opportunity to differentiate between the vari-

TABLE 6. SUMMARY OF NITROGEN RECOVERIES IN CROP AND LEACHING FROM 200 POUNDS OF NITROGEN IN VARIOUS MATERIALS, 1930-'39
WINDOR LYSIMETER SERIES B.
(In pounds per acre, per year.)

Treatment	Nitrogen removed in crop	Nitrate nitrogen: Leaching by periods				Nitrate nitrogen: Total leaching year	Ammonia nitrogen leached year	Total nitrogen recovery in crop and leaching	Standard error of total replicate tanks[1]
		June-Aug.	Sept.-Nov.	Dec.-Mar.	Apr.-May				
Nitrate of soda	90.5	28.1	61.7	32.3	2.9	125.0	0.9	**216.4**	7.3
Nitrate of potash	92.1	23.1	53.0	35.1	3.3	114.5	0.8	**207.4**	2.3
Nitrate of lime	89.6	24.9	55.1	34.2	4.3	118.5	0.5	**208.6**	2.7
Sulfate of ammonia	61.2	14.4	55.0	37.6	3.1	110.1	3.3	**174.6**	6.5
Ammophos	81.8	9.7	40.6	41.8	4.4	96.5	0.8	**179.1**	5.3
Urea	84.4	15.9	32.7	27.5	3.9	80.0	0.4	**164.8**	0.3
Calurea	90.1	17.4	43.0	29.0	4.3	93.7	0.4	**184.2**	4.7
Cyanamid	82.2	10.6	34.6	33.1	5.1	83.4	0.6	**166.2**	2.1
Cottonseed meal	74.4	12.8	27.5	24.5	5.0	69.8	0.5	**144.7**	3.5
Castor pomace	72.1	15.8	33.4	28.2	3.6	81.0	0.6	**153.7**	1.6
Linseed meal	73.6	13.1	30.9	27.3	5.1	76.4	0.6	**150.6**	1.0
Fish meal	78.8	13.2	29.2	26.9	4.8	74.1	0.6	**153.5**	0.5
Dried blood	77.1	13.4	35.2	30.4	5.0	84.0	0.4	**161.5**	8.2
Tankage	82.8	13.7	31.6	27.4	4.7	77.4	0.5	**160.7**	7.1
Manure	47.4	10.8	25.0	23.7	6.4	65.9	0.5	**113.8**	3.4
No Nitrogen	18.7	3.6	10.2	12.1	2.2	28.1	0.5	**47.3**	1.5

[1] Standard error of all replications, for mean total—4.3.

ous treatments. Conditions when the leaching during the early growing season was of sufficient magnitude to seriously deplete the nitrate nitrogen in the soil were lacking in this experiment. Thus one objective of the experiment was not achieved. In field trials in a somewhat more sandy soil on one of the Windsor fields, tobacco fertilized with nitrate of soda as the sole source of nitrogen, in a single application before planting, has shown definitely that the nitrates had been leached from the root zone during the growing season to a degree causing nitrogen deficiency in the crop. In the same seasons, when other materials, such as cottonseed meal or urea, were used as the source of nitrogen, the crops were able to obtain favorable amounts. This has been reported in detail by Anderson and others in a previous publication of this Station (2).

The greater early leaching of nitrates from nitrate materials in the present experiment has been compensated by the greater amounts of available nitrogen that they have supplied. The three nitrates are significantly higher in total nitrogen recovery than all of the other nitrogenous fertilizers. As would be expected, calurea, with one-fifth of the nitrogen as the nitrate, gives a higher liberation of nitrogen than other materials containing no nitrates. Inorganic ammoniates give slightly higher total nitrogen recovery than urea or cyanamid. The "animal" organics (dried blood and tankage) show somewhat higher availability than the oil seed materials (cottonseed meal, castor pomace and linseed meal). Manure is in a class by itself as very materially lower in nitrogen availability than other nitrogenous fertilizers.

Even the nitrate salts have failed to give total nitrogen recoveries exceeding the nitrogen liberation from the "no nitrogen" treatment by the amount applied to the soil (200 pounds per acre per year). This seems to indicate a lower liberation of nitrogen from the humus material of the soil itself when the nitrogen is supplied by the fertilizer. This is a logical result, since the micro-organisms concerned in nitrogen transforming processes may be expected to attack the complex organic nitrogen compounds of the soil to a lesser degree when supplied with more readily available sources. This is also linked with the greater root residues remaining in the soil from the larger crops produced when nitrogen is added in the fertilizer.

No outstanding differences in relative nitrate leachings in the different periods have been in evidence for the various nitrogen materials that must be transformed to nitrates by soil micro-organisms.

The low early leaching of nitrates from ammophos seems to suggest a slower formation of nitrates from this material. This might also have been true for sulfate of ammonia if its crop recovery had been normal. In spite of the fact that cyanamid is applied four weeks before the other materials, its liberation as nitrates is somewhat retarded. The results with castor pomace suggest a more rapid early nitrification than from other organics. The slow availability

of manure is well shown by the distribution of nitrates in the various periods of leaching.

The characteristics of nitrate leaching for the various classes of fertilizer nitrogen are summarized in the data shown as Table 7.

TABLE 7. RELATIVE NITRATE NITROGEN LEACHING FROM VARIOUS FORMS OF NITROGEN BY PERIODS, LYSIMETER SERIES B, AVERAGE OF NINE YEARS: 1930-'39.

Class of nitrogen source	Number of materials studied	Nitrate nitrogen leached per year, pounds per acre	Percentage of total yearly leaching, by periods			
			June-Aug.	Sept.-Nov.	Dec.-Mar.	Apr.-May
Nitrate salts	3	119.2	21.4	47.5	28.4	2.7
Ammonia salts	2	103.4	11.7	46.2	38.4	3.7
Urea and cyanamid	2	81.8	16.3	41.2	37.0	5.5
Animal-derived organics	3	78.4	17.1	40.8	36.0	6.1
Oil seed meals	3	75.7	18.4	40.4	35.1	6.1
Cow manure	1	65.0	16.4	37.9	36.0	9.7
Soil nitrogen	—	28.1	12.8	36.3	43.1	7.8
		Inches				
Volume of leaching		14.5	9.6	31.7	42.4	16.3

CUMULATIVE EFFECTS OF NITROGENOUS FERTILIZERS ON THE NITROGEN AND ORGANIC MATTER CONTENT OF THE SOIL

Samples of soil from the three distinct layers, as placed in the tanks and as removed from each tank after eleven years, have been analyzed for total nitrogen and organic matter, as shown by the data of Table 8. The samples of the subsoil (B) and substratum (C) layers at the end of the experiment showed only slight differences with respect to both nitrogen and organic matter, as compared with the original samples. The 1940 samples averaged slightly lower in the subsoil and almost the same in the substratum (189 pounds) as 11 years previously. The organic matter measurements showed similar results in the lower layers. The effects of the treatments were chiefly confined to the upper 7 inches, or surface soil.

In most cases the data on total nitrogen recovery in the harvested crop, as nitrates and as ammonia during the 11-year period in relation to the amount applied in the treatment, indicated that there should be a considerable residual effect upon the nitrogen in the soil. In a few cases losses were indicated. The soil data tend to confirm their changes, but are of somewhat different magnitude, in several instances. This comparison is shown in Table 9.

The statistical standard errors,. based on two measurements of each soil layer from each of the two replicate tanks, represent from 46 to 105 pounds of nitrogen, and from 207 to 611 pounds of organic matter, per acre, for the entire profile. Hence, many of the differences represented by the soil analyses may be considerd as significant.

It is somewhat difficult to explain the unusual loss of organic matter under the nitrate of soda treatment, and the unusual gain result-

TABLE 8. NITROGEN AND ORGANIC MATTER IN SOIL LAYERS, WINDSOR LYSIMETER SERIES B, AS REMOVED FROM THE TANKS, APRIL, 1940.

Nitrogen treatment (ten years)	Nitrogen (in percent)			Organic matter (in percent)		
	Surface soil A	Subsoil B	Substratum C	Surface soil A	Subsoil B	Substratum C
Nitrate of soda	.0608	.0190	.0115	1.983	.514	.553
Nitrate of potash	.0615	.0155	.0137	2.121	.693	.543
Nitrate of lime	.0583	.0178	.0125	2.093	.581	.584
Sulfate of ammonia	.0705	.0159	.0105	2.207	.529	.564
Ammophos	.0740	.0173	.0134	2.098	.550	.517
Urea	.0760	.0163	.0118	2.058	.545	.574
Calurea	.0718	.0220	.0125	2.014	.612	.497
Cyanamid	.0660	.0185	.0128	1.983	.565	.553
Cottonseed meal	.0805	.0170	.0133	2.243	.586	.559
Castor pomace	.0763	.0160	.0130	2.643	.597	.538
Linseed meal	.0755	.0168	.0143	2.115	.565	.564
Fish meal	.0718	.0158	.0128	1.993	.571	.548
Dried blood	.0800	.0160	.0158	2.072	.662	.497
Tankage	.0788	.0160	.0155	2.126	.628	.512
Cow manure	.1035	.0194	.0168	2.707	.597	.491
No nitrogen	.055	.0143	.0155	1.876	.581	.507
Original soil, 1929	.0620	.0225	.0130	2.174	.733	.483

ing from castor pomace. The drainage water from the soil treated with nitrate of soda was usually somewhat discolored, in contrast to all other treatments. No measurement of organic matter in the drainage water was made. However, it seems unlikely that this should have been of significant magnitude. Castor pomace contains much more lignin and cellulose, resistant to decay, than the other materials.[1] The amounts of castor pomace applied in ten years were approximately 42,000 pounds per acre.

TABLE 9. NET EFFECTS OF VARIOUS NITROGEN TREATMENTS ON NITROGEN AND ORGANIC MATTER OF THE SOILS IN LYSIMETER SERIES B, IN RELATION TO NITROGEN REMOVED BY LEACHING AND TOBACCO CROP.
(Pounds per acre.)

Treatment	Total nitrogen recovery in crop and leaching	Expected soil gain or loss	Determined soil gain or loss[2]	Organic matter net gain or loss[3]
Nitrate of soda	2161	74 loss	147 loss	10,543 loss
Nitrate of potash	2110	68 loss	197 loss	3,011 loss
Nitrate of lime	2113	71 loss	224 loss	6,161 loss
Sulfate of ammonia	1833	209 gain	24 loss	3,819 loss
Ammophos	1853	189 gain	136 gain	6,396 loss
Urea	1678	364 gain	137 gain	6,648 loss
Calurea	1879	163 gain	44 gain	6,872 loss
Cyanamid	1630	412 gain	75 gain	8,117 loss
Cottonseed meal	1506	536 gain	431 gain	1,465 loss
Castor pomace	1588	454 gain	175 gain	7,749 gain
Linseed meal	1565	477 gain	147 gain	4,927 loss
Fish meal	1560	482 gain	62 gain	7,729 loss
Dried blood	1676	366 gain	267 gain	4,138 loss
Tankage	1650	392 gain	239 gain	3,638 loss
Manure	1192	850 gain	921 gain	8,563 gain
No nitrogen	524	482 loss	373 loss	10,744 loss

[1] Recent unpublished data reported to us by E. J. Rubins, New Jersey Agricultural Experiment Station, show castor pomace as containing 32.2 percent of lignin and 11.7 percent of cellulose, as compared with 5.4 percent and 7.9 percent respectively, for the same constituents in cottonseed meal.

[2] Total nitrogen in the three layers of original soil—2,238 pounds.

[3] Total organic matter in the three layers of original soil—77,288 pounds.

RESIDUAL AVAILABLE NITROGEN AFTER TEN YEARS OF TREATMENT

In 1939 the soils in all tanks were given a uniform fertilizer treatment, without nitrogen, identical to that used in the "no nitrogen" tanks in previous years. The results give a measure of the availability of residual nitrogen from the various treatments. Data for the nitrogen in the harvested tobacco plants and in the drainage water during this year are given in Table 10.

Table 10. Liberation of Nitrogen from the Soil in the First Year After Ten Years of Treatment, Windsor Lysimeter Series B, 1939-'40. (Pounds per acre.)

Treatment	Nitrogen in harvested tobacco crop	Nitrate nitrogen		Ammonia nitrogen leached year	Total
		Leached first period	Leached second period		
Nitrate of soda	19.4	14.3	8.5	1.0	43.2
Nitrate of potash	17.4	17.0	9.2	.9	44.5
Nitrate of lime	18.0	19.2	8.1	.7	46.0
Sulfate of ammonia	11.3	10.8	8.8	.9	30.9
Ammophos	16.8	14.0	8.5	1.3	40.6
Urea	16.7	14.9	11.0	.5	43.1
Calurea	18.4	14.5	8.4	.2	41.5
Cyanamid	24.4	13.0	4.2	.3	41.9
Cottonseed meal	30.9	32.4	17.5	1.0	81.8
Castor pomace	21.8	24.2	12.1	.4	58.5
Linseed meal	27.3	32.1	17.5	.2	77.1
Fish meal	26.3	28.5	14.1	.1	69.0
Dried blood	27.8	22.7	15.5	.2	66.2
Tankage	30.3	29.6	14.7	.4	75.0
Cow manure	53.1	28.0	17.1	.6	98.8
No nitrogen	15.5	12.7	6.3	.6	35.1

With the exception of sulfate of ammonia, all of the inorganic or synthetic nitrogen materials showed slight but consistent amounts of residual available nitrogen, in excess of that liberated from a soil not receiving nitrogen in the fertilizer during the entire experiment. This averaged 4.3 pounds per acre, chiefly reflected in crop increase. Sulfate of ammonia appeared to have a slight adverse residual effect upon nitrogen liberation.

The residual nitrogen from the various organic materials was of substantial magnitude, varying from 23 to 46 pounds per acre more than the "no nitrogen" check treatment. As would be expected, cow manure showed the most notable residual effect.

It should be borne in mind that the original soil in this experiment, under continuous tobacco culture, had been fertilized for many years with fertilizer containing chiefly organic nitrogen. The liberation of nitrogen on the "no nitrogen" treatment averaged 70 pounds per acre during the first three years (1929-'32); 40 pounds during the

next five years (1932-'37); and 37 pounds during the last three years (1937-'40).

As a further evidence of residual nitrogen from past treatment, the "hoof and horn meal" applications to tanks 125 and 126 were discontinued after the first three years, and the tanks were continued as a "no nitrogen," without crop control during the remaining years. During the 1929-'32 period, the liberation of nitrogen from hoof and horn meal was comparable to that from tankage or dried blood, approximately 160 pounds per acre per year in crop and leaching. During the next three years, the average annual leaching of nitrogen, under bare soil was 71 pounds, and for the last five years, 47 pounds. The residual available nitrogen from high grade organic nitrogenous materials, such as used in this experiment and in general for tobacco fertilization, is of little consequence after the third year without such fertilizer.

CROP REMOVALS AND DRAINAGE WATER LOSSES OF SEVERAL CONSTITUENTS FROM SOILS FERTILIZED WITH VARIOUS NITROGENOUS FERTILIZERS

The nine years (1930-'39) in which nitrogen treatments were applied and crops were harvested, afford a good comparison of the liberation of the various basic and acidic constituents to the crop and to the drainage water. These data are compiled as Table 11. It does not include nitrogen, previously covered in Table 6.

Calcium losses from the soil by leaching were of much greater magnitude than crop intake, ranging from two and one-half to three times the latter, in most cases. Nitrate of lime, supplying the greatest amount of calcium, produced largest leaching and crop removals. Sulfate of ammonia, supplying no calcium except that contained in the precipitated bone fertilizer, caused much leaching of calcium, but the crop obtained little. In other cases the calcium removals tended to follow the nitrogen recoveries.

Magnesium is obtained by the crop to a much greater relative degree. In some cases the crop intake exceeded the amount lost by leaching. Ammophos and sulfate of ammonia caused greatest removals of magnesium from the soil.

Potassium, supplied in much larger amount by the nitrate of potash treatment, produced larger relative increases in the leaching than in the crop. Sulfate of ammonia produced a notable increase in the leaching of this constituent. Nitrate of soda decreased the leaching loss. The leachings were similar in other cases, and the crop removal was generally in relation to the dry matter production of the crop.

Sodium was an insignificant constituent in both crop and leaching, except in case of nitrate of soda, supplying this element in a large amount. Some sodium was contributed as impurities by a few of the other materials. This was reflected in the leaching and, to some ex-

TABLE 11. YEARLY REMOVAL OF BASIC AND ACIDIC CONSTITUENTS BY LEACHING (L) AND CROP (C), WINDSOR LYSIMETER SERIES B, AVERAGE OF NINE YEARS (1930-'39)[1].
(In pounds per acre.)

Nitrogen treatment		Basic constituents					Acidic constituents		
		Calcium	Magnesium	Potassium	Sodium	Manganese	Sulfur	Chlorides	Phosphorus
Nitrate of Soda	(L)	48.1	12.7	46.0	267.4	——	72.4	13.1	0.1
	(C)	33.6	13.1	90.2	19.3	.19	4.9	8.6	7.5
	Total	**81.7**	**25.8**	**136.2**	**286.7**	**.19**	**77.3**	**21.7**	**7.6**
Nitrate of Potash	(L)	75.5	17.0	245.8	13.5	——	36.7	17.7	——
	(C)	29.9	13.6	149.4	6.1	.25	4.4	13.6	6.5
	Total	**105.4**	**30.6**	**395.2**	**19.6**	**.25**	**41.0**	**31.3**	**6.5**
Nitrate of Lime	(L)	184.1	19.4	68.0	9.0	——	62.0	13.4	——
	(C)	60.1	12.6	90.2	2.4	.30	5.6	10.2	7.1
	Total	**244.2**	**32.0**	**158.2**	**11.4**	**.30**	**67.6**	**23.6**	**7.1**
Sulfate of Ammonia	(L)	169.8	32.6	160.4	11.9	6.45	217.5	15.5	——
	(C)	20.1	7.3	51.4	1.7	1.47	11.1	7.5	5.4
	Total	**189.9**	**39.9**	**211.8**	**13.6**	**7.92**	**228.6**	**23.0**	**5.4**
Ammophos	(L)	124.8	32.4	123.8	16.2	.37	97.4	14.1	.1
	(C)	24.0	12.6	63.1	1.5	2.45	8.9	10.1	11.1
	Total	**148.8**	**44.6**	**186.9**	**17.7**	**2.82**	**106.3**	**24.2**	**11.2**
Urea	(L)	105.1	18.6	63.1	9.5	——	57.2	14.4	——
	(C)	42.6	14.4	87.0	2.4	1.65	6.1	11.1	7.0
	Total	**147.7**	**33.0**	**150.1**	**11.9**	**1.65**	**63.3**	**25.5**	**7.0**
Calurea	(L)	135.3	20.2	92.2	9.2	——	56.2	14.0	——
	(C)	49.0	14.2	91.4	2.0	1.27	6.4	11.6	7.3
	Total	**184.3**	**34.4**	**183.6**	**11.2**	**1.27**	**62.6**	**25.6**	**7.3**
Cyanamid	(L)	125.0	13.5	90.9	8.8	——	63.3	11.9	——
	(C)	49.6	9.0	88.1	2.1	.30	7.4	10.7	6.1
	Total	**174.6**	**22.5**	**179.0**	**10.9**	**.30**	**70.7**	**22.6**	**6.1**

Cottonseed Meal	(L)	88.4	19.8	105.3	10.4	——	52.5	12.9	——
	(C)	32.7	16.0	86.4	2.2	1.25	7.2	10.3	6.6
	Total	**121.1**	**35.8**	**191.7**	**12.6**	**1.25**	**59.7**	**23.2**	**6.6**
Castor Pomace	(L)	100.9	20.1	113.3	10.8	——	54.9	16.2	——
	(C)	36.1	12.7	79.9	2.1	1.34	5.9	13.3	6.1
	Total	**137.0**	**32.8**	**193.2**	**12.9**	**1.34**	**60.8**	**29.5**	**6.1**
Linseed Meal	(L)	91.2	20.2	109.3	12.2	——	55.6	14.1	——
	(C)	35.4	13.8	84.5	2.3	1.31	6.9	10.6	6.7
	Total	**126.6**	**34.0**	**193.8**	**14.5**	**1.31**	**62.5**	**24.7**	**6.7**
Fish Meal	(L)	111.1	18.3	97.4	15.7	——	66.2	16.8	——
	(C)	48.8	13.5	87.6	2.4	1.31	7.7	13.8	7.9
	Total	**159.9**	**31.8**	**185.0**	**18.1**	**1.31**	**73.9**	**30.6**	**7.9**
Dried Blood	(L)	101.1	18.7	114.1	17.6	——	59.2	16.9	——
	(C)	39.0	13.7	82.3	2.4	2.28	6.7	16.1	5.8
	Total	**140.1**	**32.4**	**196.4**	**20.0**	**2.28**	**65.9**	**33.0**	**5.8**
Tankage	(L)	107.4	20.8	98.8	22.6	——	74.6	19.0	——
	(C)	50.1	14.6	96.1	2.7	1.24	7.6	17.4	8.3
	Total	**157.5**	**35.4**	**194.9**	**25.3**	**1.24**	**82.2'**	**36.4**	**8.3**
Cow Manure	(L)	81.0	20.8	97.8	19.4	——	53.6	21.1	——
	(C)	33.2	13.0	71.7	2.1	.16	6.7	14.6	7.5
	Total	**114.2**	**33.8**	**169.5**	**21.5**	**.16**	**60.3**	**35.7**	**7.5**
No Nitrogen	(L)	59.1	11.1	92.1	7.4	——	66.3	13.6	——
	(C)	13.0	4.9	35.7	1.2	.12	4.9	6.3	4.2
	Total	**72.1**	**16.0**	**127.8**	**8.6**	**.12**	**71.2**	**19.9**	**4.2**

[1] See Table 6 for data on nitrogen, leached as nitrates and ammonia, and removed by crop.

tent in the crop, conspicuously in the cases of nitrate of potash, fish meal, dried blood, tankage and manure.

Manganese was present in the leaching in determinable amount only in the case of sulfate of ammonia and ammophos, the two most acid-producing materials. Manganese was present in the crop in general agreement with the effect of the fertilizer upon soil acidity, as will be discussed later. It is likely that some manganese dissolved in the soil solution in the surface soil layer was moved downward by leaching into the subsoil but, except as noted above, was retained in the lower soil layers.

Sulfur, supplied in large amounts by sulfate of ammonia and in considerable quantity by ammophos, was most leached from the soil under these treatments. However, the crop showed no great increase in intake when the sulfur was thus supplied. Leaching losses greatly exceeded crop removals.

Chlorine was readily taken up by the crop in general to a smaller relative extent when the nitrate supply in the soil was most abundant. Leaching losses were of similar magnitude to crop assimilations. Chlorides, present in various treatments as impurities and supplied to some extent by rainfall, were quantitatively recovered in the crop and leaching.

Phosphorus did not leach. Amounts removed by the crop were in relation to the amount of growth, except in the case of ammophos, supplying over six times as much phosphorus to the soil as most other treatments. The crop obtained nearly twice as much phosphorus. The additional phosphorus supplied by tankage was slightly reflected in the crop intake.

Inter-relations between various constituents assimilated by the crop and liberated from the soil to the drainage water will be discussed in a later section of this bulletin.

Net Soil Gains or Losses of Various Constituents

The amounts applied in the treatments and brought into the soil by atmospheric precipitation (see Table 2) may be compared with the total quantities removed by crop and drainage water during the 11 years of the experiment. The latter are summarized in Table 12. The computed net gains or losses, obtained by comparing the data in Table 12 with that of Table 2, are shown in Table 13.

Calcium was removed from the soil in greater amounts than applied, in most cases. The acid-reacting materials produced the greatest net loss. Manure, cyanamid and nitrate of lime, supplying large amounts of calcium, caused net gains. (It must be considered that the manure used in this experiment contained limestone.) It seems likely that fish meal supplied more calcium than had been computed from its composition. The net gain from the "no nitrogen" treatment is apparently associated with the smaller amounts of nitrates avail-

TABLE 12. TOTAL REMOVALS OF VARIOUS CONSTITUENTS BY BOTH LEACHING AND CROP DURING THE 11-YEAR PERIOD (1929-'40)
WINDSOR LYSIMETER SERIES B.
(In pounds per acre.)

Treatment	Calcium	Magnesium	Potassium	Sodium	Manganese	Sulfur	Chlorine	Phosphorus
Nitrate of soda	896	255	1375	2833	1.8	813	233	73
Nitrate of potash	1170	317	3832	213	2.4	435	317	62
Nitrate of lime	2491	323	1527	141	2.8	677	242	68
Sulfate of ammonia	2015	417	2017	150	73.5	2271	241	51
Ammophos	1609	462	1799	195	25.9	1085	252	106
Urea	1541	346	1799	131	15.1	634	261	67
Calurea	1807	352	1770	139	11.7	621	264	69
Cyanamid	1769	233	1738	138	2.9	713	233	60
Cottonseed meal	1282	366	1870	143	11.7	562	245	64
Castor pomace	1447	332	1880	151	12.4	618	307	58
Linseed meal	1349	353	1880	168	11.8	624	263	63
Fish meal	1660	322	1790	198	12.2	747	334	76
Dried blood	1481	345	1905	228	21.0	654	295	56
Tankage	1635	358	1885	280	11.6	771	346	80
Cow manure	1224	366	1672	235	1.6	626	360	75
No nitrogen	765	181	1288	106	1.2	696	203	41

Table 13. Computed Net Gains (+) or Losses (—) to Soils Under Various Nitrogen Treatments, With Respect to Constituents Other Than Nitrogen, Windsor Lysimeter Series B.
(In pounds per acre.)

Treatment	Calcium	Magnesium	Potassium	Sodium	Sulfur	Chlorine	Phosphorus
Nitrate of soda	15+	100+	559+	170+	158—	12—	408+
Nitrate of potash	259—	38+	2044+	13—	44—	13—	419+
Nitrate of lime	945+	32+	407+	12+	22—	2+	413+
Sulfate of ammonia	1104—	62—	83—	29+	670+	37+	430+
Ammophos	1051—	107—	135+	19—	198+	21+	2899+
Urea	630—	9+	135+	19+	21+	21—	414+
Calurea	324—	3+	164+	15+	34+	19—	412+
Cyanamid	2992+	122+	196+	0	23—	9—	421+
Cottonseed meal	822—	11—	64+	5+	5+	7—	417+
Castor pomace	770—	31—	54+	24+	56—	35—	423+
Linseed meal	722—	41+	54+	3—	47—	4—	418+
Fish meal	9+	33+	144+	5—	51—	26—	897+
Dried blood	893—	10+	29+	0	47+	32+	425+
Tankage	116—	3—	49+	1+	96—	21+	620+
Cow manure	3012+	512+	79+	0	29+	7+	498+
No nitrogen	146+	174+	646+	17+	41—	2+	440+

able for combining with this base. In case of nitrate of soda, the nitrates were leached largely in combination with sodium, thus permitting a slight gain.

Magnesium was generally removed from the soil in quantities similar to amounts entering the soil. The only substantial depletions were caused by ammophos and sulfate of ammonia. In most cases the net gains or losses were of insignificant magnitude. The large net gain in case of cow manure was presumably related to its contamination with limestone.

Potassium showed net gains in all cases, except for the sulfate of ammonia treatment. As expected, the largest net gain was from the nitrate of potash treatment.

Sodium in nitrate of soda appeared to produce a slight accumulation in the soil. However, this was insignificant in relation to the total application. In other cases the removal by leaching and crop was in close agreement with the amount brought to the soil by atmospheric precipitation and in the treatments.

Sulfur, applied in large quantities in sulfate of ammonia, and in ammophos, showed net gains. They were relatively small in proportion to the amounts applied. In other cases, the removal from the soil was similar to the amounts in the treatments and in the rainfall.

Chlorine was removed from the soil by leaching and crop in almost identical amounts to those supplied by atmospheric precipitation and as impurities in the various treatments. The small discrepancies are no greater than would be expected from errors in chemical analysis.

SOIL CHANGES RESULTING FROM NITROGENOUS FERTILIZERS AS REFLECTED BY SOIL ANALYSES

Exchangeable Bases

The most important feature of soil changes produced by nitrogenous fertilizers is with respect to their content of readily replaceable (exchangeable) bases. This is directly related to soil acidity, since depletion of soil bases lowers the degree of base saturation, thus increasing the acidity through an increase in exchangeable hydrogen. Measurements of bases replaced by ammonium acetate solution (normal) for each of the three soil layers have been computed to pounds per acre, on the basis of the acre weight of the fine soil (2 millimeters) in each layer. Separate data for each layer is presented on a different basis in a later section (See Tables 18, 19 and 20). The totals for the entire soil profile are shown in Table 14. These are also compared with the data for the soil as placed in the lysimeters in 1929. A calculation of the combined net changes in the four bases, on the basis of calcium carbonate equivalent, is included. The latter indicates the amount of limestone that would be required to compensate for the loss, or that is replaced in overcoming soil acidity by the net gain.

Table 14. Basic Soil Constituents Extractable With Ammonium Acetate Sampled at End of Experiment, in Comparison with Original Soil Exchangeable Bases, Windsor Lysimeter Series B.
(In pounds per acre, for the entire soil profile in the tanks.)

Nitrogen materials	Calcium		Magnesium		Potassium		Sodium		Calcium carbonate equivalent total change
	Final	Change	Final	Change	Final	Change	Final	Change	
Nitrate of soda	1200	152+	376	104+	1294	316+	205	148+	1535+
Nitrate of potash	950	98—	304	32+	2244	1257+	71	14+	1496+
Nitrate of lime	1703	655+	247	25—	878	109—	68	11+	1391+
Sulfate of ammonia	266	782—	159	113—	403	584—	73	16+	3129—
Ammophos	339	709—	222	50—	614	373—	63	6+	2439—
Urea	648	400—	334	62+	784	203—	64	7+	988—
Calurea	814	234—	313	41+	800	187—	62	5+	643—
Cyanamid	2713	1665+	249	23—	791	196—	54	3—	3801+
Cottonseed meal	575	473—	278	6+	665	322—	65	8+	1549—
Castor pomace	598	450—	268	4—	595	392—	58	1+	1607—
Linseed meal	550	498—	284	12+	689	298—	50	7—	1590—
Fish meal	747	301—	287	15+	602	385—	81	24+	1129—
Dried blood	540	508—	311	39+	692	295—	47	10—	1507—
Tankage	549	499—	262	10—	683	304—	50	7—	1690—
Cow manure	2801	1753+	579	307+	807	180—	44	13—	5378+
No nitrogen	1042	6—	394	122+	1155	168+	45	12—	676+
Original soil—1929	1048	——	272	——	987	——	57	——	

Net gains or losses of exchangeable calcium generally follow the same trends as indicated in Table 13. However the change is usually of less magnitude. In two cases, fish meal and no nitrogen, the soil analyses showed losses in calcium, although the lysimeter data indicated gains in this constituent.

Magnesium changes are of similar magnitude and trends for both computations. In three instances, nitrate of lime, cyanamid and cottonseed meal, there is a slight difference in the trend.

Potassium, applied to the soil in greater amounts than leached or removed by cropping, except in one instance, was not recovered from the soil by the "base exchange" measurement in corresponding amounts. On the average, approximately 450 pounds of the potassium applied during the 11 years appear to have been fixed in the soil in non-exchangeable form. This is in agreement with previous findings in Lysimeter Series "A" (14), and with those of numerous other investigations concerning potassium fixation. When this allowance is made, the effects of the treatments upon the exchangeable bases are generally in agreement with the trends indicated in Table 13.

The small residue of sodium, not leached or removed by the crop, under the nitrate of soda treatment was mostly retained in the soil in the exchangeable form. In other cases, the differences in either direction in both comparisons are of insignificant magnitude.

The calculated net effect on the lime requirement of the soil will be discussed in a later section.

Total and Available Phosphorus

Chemical analyses of the various soil layers removed from the lysimeter tanks in 1940 included determinations of both total phosphorus contents and the amounts extractable by the "available" phosphorus method of Truog. The data are shown in Tables 15 and 16.

The total phosphorus results are in remarkably good agreement with the lysimeter data regarding net gains during the experiment, as shown previously in Table 13. The increases in phosphorus, resulting from the fact that much greater amounts of this element were applied in the fertilizer than could be removed by the crop, are clearly shown. This is especially true when unusually high amounts were applied, as in case of ammophos and, to a lesser degree, from fish meal, tankage and manure treatments, all of which supplied more than the usual amounts of phosphorus.

It is to be noted that practically all of the accumulating phosphorus is represented in the surface soil. The only exceptions are those of nitrate of soda, nitrate of potash and ammophos, where there are significant gains in the subsoil, and even in the substratum, as in case of nitrate of soda. The gain in the subsoil from the ammophos treatment is probably due to the unusually high rate of application.

Nitrate of soda and, to a lesser degree, nitrate of potash tend to permit greater downward movement of phosphorus, probably due to some formation of the more soluble phosphates of the sodium or potassium bases. It is to be noted that the drainage waters from the nitrate of soda tanks were the only ones to show leaching of measurable amounts of phosphorus.

The data on available phosphorus give a much different picture. The gain in total phosphorus was rarely associated with a corresponding or proportionate gain in available phosphorus. In several cases,

Table 15. Phosphorus (Total) in Soils, as Removed from Lysimeter Series B.

Nitrogen treatment	Percent in various soil layers			Entire profile in tanks pounds per acre	Net gain
	Surface soil A	Subsoil B	Substratum C		
Nitrate of soda	.1372	.0483	.0314	4864	464
Nitrate of potash	.1375	.0425	.0293	4763	363
Nitrate of lime	.1483	.0344	.0287	4777	337
Sulfate of ammonia	.1520	.0344	.0290	4865	425
Ammophos	.2571	.0476	.0280	7638	3238
Urea	.1486	.0340	.0293	4780	380
Calurea	.1516	.0341	.0287	4844	440
Cyanamid	.1459	.0317	.0303	4668	468
Cottonseed meal	.1500	.0337	.0303	4818	478
Castor pomace	.1503	.0337	.0290	4807	407
Linseed meal	.1490	.0359	.0283	4814	414
Fish meal	.1671	.0344	.0280	5198	798
Dried blood	.1449	.0357	.0287	4735	335
Tankage	.1675	.0351	.0270	5214	814
Manure	.1564	.0374	.0303	5068	668
No nitrogen	.1540	.0377	.0290	5014	614
Original Soil, 1929	.1313	.0350	.0286	4400	——

Table 16. "Available" Phosphorus (Truog Method) in Soils, as Removed from Lysimeter Series B.

Nitrogen treatment	P. P. M. in various soil layers			Entire profile in tanks pounds per acre	Net gain or loss
	Surface soil A	Subsoil B	Substratum C		
Nitrate of soda	288	44	15	806	165+
Nitrate of potash	274	26	15	724	83+
Nitrate of lime	290	12	11	716	75+
Sulfate of ammonia	174	7	11	435	206—
Ammophos	251	44	10	714	73+
Urea	207	7	10	510	131—
Calurea	238	7	9	580	61—
Cyanamid	465	10	10	1112	471+
Cottonseed meal	173	7	9	431	210—
Castor pomace	175	10	9	444	197—
Linseed meal	180	11	12	462	179—
Fish meal	333	11	9	810	169+
Dried blood	166	8	9	417	224—
Tankage	321	9	9	776	135+
Manure	410	15	10	1000	359+
No nitrogen	319	18	8	781	140+
Original soil, 1929	244	24	9	641	——

the Truog method measured less available phosphorus than in the original soil. These instances were generally associated with treatments that produced increasing soil acidity, unless an unusual amount of phosphorus was applied. When gains were obtained, the treatments had caused a lowering of acidity (higher pH), under equal phosphorus treatments. Larger amounts of total phosphorus in the subsoils from certain treatments were paralleled by increasing amounts of available phosphorus, presumably due to the factors discussed in the preceding paragraph.

Total Potassium

Determinations of total potassium in the soils were made in all cases. However, the variance of the results from replicate tanks was too great to permit measurement of significant differences between treatments. This is not surprising, since the total amount of potassium in the soil profile represents nearly 90,000 pounds per acre, and the difference that could be expected to result from even the unusually high potassium accumulation under nitrate of potash is only slightly more than 2 percent of this (see Table 13).

Moisture Equivalent

The moisture equivalents of the surface soil (A) samples, from tanks treated with manure showed a final average of 9.85 percent. This was 0.88 percent higher than the average of soils under all other treatments (8.97 percent). This is a reasonable result when the increase in organic matter is considered. No other treatment produced an appreciable or consistent change in the soil from this standpoint. However, it is to be noted that the "No nitrogen" treatment showed the lowest final moisture equivalent, at 8.42 percent, presumably in consequence of the loss in organic matter. The large gain in organic matter, as measured by the carbon determination from castor pomace (see Table 9) was not reflected in the moisture equivalent to a significant degree. There was no effect of any treatment upon the subsoil (B) or substratum (C) samples. The averages for these horizons, for all tanks, were 7.00 percent and 6.11 percent respectively.

SOIL CHANGES FROM NITROGENOUS FERTILIZERS, AS RELATED TO SOIL ACIDITY

Samples of the surface soil, to the depth of 7 inches, were drawn from year to year to evaluate progressive effects of the treatments. A summary of these data is shown in Table 17. The measurements were made either in late fall, or in the early spring of the following year, in each case.

The pH measurements during the first six years were by the quinhydrone electrode. Since 1936 the glass electrode method has been employed.

After the fourth year, the reactions of the surface soil had apparently attained an equilibrium under a given treatment that was

quite constant in most cases. It is to be noted that the soils received no nitrogen treatment in 1939, prior to the final pH measurements in the spring of 1940.

The details of the leachings of calcium from year to year in the course of this experiment evidence the fact that the net gains or losses were much more pronounced during the first four years, under those treatments that produced the more acid conditions. The average yearly leachings of calcium during the first four years were from 1½ to 2½ times as great as during the last four years of treatment.

Table 17. pH Measurements of Surface Soil (A), in Fall or Early Spring Following Each Yearly Treatment, Windsor Lysimeter Series B, 1929-40.

Nitrogen Treatment	Year of experiment										
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Final
Nitrate of soda	6.1	5.4	6.4	6.5	6.3	6.9	6.9	6.8	7.0	6.9	5.9
Nitrate of potash	6.2	5.2	6.3	6.5	6.3	6.7	6.6	6.7	6.6	6.9	6.1
Nitrate of lime	6.0	5.1	6.3	5.9	5.8	6.1	6.0	6.1	6.1	6.2	5.8
Sulfate of ammonia	4.9	4.4	5.3	4.0	4.0	4.3	4.2	4.0	4.0	4.2	4.2
Ammophos	5.0	4.3	4.8	4.1	4.1	4.2	4.2	4.3	4.3	4.5	4.4
Urea	5.5	4.8	5.4	5.1	4.9	5.3	5.1	4.9	4.8	5.1	5.0
Calurea	6.0	5.1	5.7	5.3	5.1	5.5	5.4	5.2	5.2	5.3	5.0
Cyanamid	7.5	7.2	7.1	6.8	6.3	7.0	7.4	7.2	7.1	7.4	6.8
Cottonseed meal	5.3	4.6	5.6	5.1	5.0	5.3	4.9	5.0	4.8	4.9	4.7
Castor pomace	5.2	4.6	5.4	5.0	4.9	5.1	4.9	4.8	4.9	4.8	4.8
Linseed meal	5.4	4.5	5.6	5.0	5.1	5.0	4.9	4.8	4.8	4.9	4.7
Fish meal	5.3	4.7	5.3	5.1	5.0	5.1	4.9	4.9	4.9	5.0	4.9
Dried blood	4.9	4.6	5.4	4.7	4.7	4.9	4.8	4.8	4.7	4.9	4.7
Tankage	5.6	4.7	5.4	4.9	5.0	5.3	5.0	4.8	4.9	5.1	5.0
Manure[1]	6.4	5.8	6.2	6.2	6.1	6.8	6.4	6.8	6.5	6.8	6.5
No nitrogen	6.1	5.6	6.2	6.0	5.7	6.3	5.9	6.3	6.0	6.4	5.9

[1] Containing some limestone.

A more comprehensive evaluation of the effects of the various treatments in relation to soil acidity is obtained from the detailed base exchange studies of the final soil samples collected in 1940. These results are tabulated in Tables 18, 19 and 20, for the surface soils, subsoils and substratum samples, respectively. The effects of the different nitrogenous fertilizers on the individual exchangeable bases have been discussed in a previous section. Our present concern is with the total of the exchangeable bases, in equivalent terms, in relation to the base exchange capacity.

The nitrogenous fertilizers of the more acid type (sulfate of ammonia and ammophos) have depleted the exchangeable bases to a very low relative base saturation throughout the soil profile. The other materials have produced no appreciable effects in the subsoil and substratum layers. However, manure (containing limestone) had a more definite tendency than the other materials towards increasing the base status of the lower soil horizon.

The pH values in the substratum samples were increased by the nitrate materials to a greater degree than would be expected from their total exchangeable bases. However, with so low a base ex-

TABLE 18. BASE EXCHANGE DATA, SURFACE SOILS (A), LYSIMETER SERIES B, SAMPLED APRIL, 1940, AFTER 11 YEARS IN LYSIMETERS. (Results in mgm. equivalent per 100 gms. soil.)

Nitrogen treatment (10 years)	Exchangeable bases					Exchangeable H	Base exchange capacity	Relative base saturation %	Final pH
	Ca	Mg	K	Na	Total				
Nitrate of soda	1.59	.87	.81	.08	**3.35**	1.90	5.25	63.8	5.90
Nitrate of potash	1.19	.53	1.09	.06	**2.87**	2.38	5.28	54.4	6.12
Nitrate of lime	2.24	.48	.46	.06	**3.24**	2.23	5.47	59.2	5.83
Sulfate of ammonia	0.33	.21	.22	.07	**0.83**	5.40	6.23	13.3	4.25
Ammophos	0.41	.35	.44	.06	**1.26**	6.09	7.35	17.1	4.38
Urea	0.69	.49	.41	.06	**1.65**	4.20	5.85	28.2	5.03
Calurea	0.88	.32	.44	.06	**1.70**	4.40	6.10	27.9	5.00
Cyanamid	4.94	.36	.49	.06	**5.85**	1.30	7.15	81.8	6.82
Cottonseed meal	0.50	.31	.24	.06	**1.11**	4.94	6.05	18.3	4.69
Castor pomace	0.50	.23	.24	.05	**1.02**	5.01	6.03	16.9	4.80
Linseed meal	0.46	.24	.30	.05	**1.05**	5.17	6.22	16.9	4.72
Fish meal	0.74	.34	.27	.07	**1.42**	4.89	6.31	22.5	4.91
Dried blood	0.49	.46	.31	.06	**1.32**	5.19	6.51	20.3	4.68
Tankage	0.47	.35	.34	.05	**1.21**	4.62	5.83	20.8	4.97
Manure (limed)	4.85	1.12	.47	.04	**6.48**	1.43	7.91	81.9	6.48
No nitrogen	1.41	.71	.65	.02	**2.79**	2.93	5.72	48.8	5.88
Original soil, 1929	1.33	.38	.43	.03	**2.17**	3.09	5.26	41.3	5.17

TABLE 19. BASE EXCHANGE DATA, SUBSOILS (B), LYSIMETER SERIES B, SAMPLED APRIL, 1940, AFTER 11 YEARS IN LYSIMETERS.
(Results in mgm. equivalent per 100 gms. soil.)

Nitrogen treatment (10 years)	Exchangeable bases					Exchangeable H	Base exchange capacity	Relative base saturation %	Final pH
	Ca	Mg	K	Na	Total				
Nitrate of soda	.58	.35	.43	.09	1.45	1.05	2.50	58.0	6.46
Nitrate of potash	.51	.41	.84	.05	1.81	1.32	3.13	57.8	6.43
Nitrate of lime	.81	.30	.32	.05	1.48	1.31	2.79	53.0	6.03
Sulfate of ammonia	.13	.20	.15	.04	0.52	1.93	2.45	21.2	4.41
Ammophos	.17	.26	.14	.04	0.61	2.09	2.70	22.6	4.88
Urea	.33	.41	.26	.04	1.04	1.36	2.40	43.3	5.18
Calurea	.45	.43	.27	.04	1.19	1.28	2.47	48.2	5.22
Cyanamid	.55	.32	.19	.03	1.09	1.33	2.42	45.0	5.26
Cottonseed meal	.38	.31	.28	.04	1.01	1.27	2.28	44.3	5.33
Castor pomace	.40	.40	.24	.04	1.08	1.29	2.37	45.6	5.45
Linseed meal	.38	.46	.26	.03	1.13	1.19	2.32	48.7	5.63
Fish meal	.46	.38	.22	.07	1.13	1.26	2.39	47.3	5.59
Dried blood	.35	.37	.24	.02	0.98	1.39	2.37	41.4	5.63
Tankage	.35	.31	.24	.03	.093	1.37	2.30	40.4	5.96
Manure (limed)	.75	.56	.23	.02	1.56	1.24	2.80	55.7	6.36
No nitrogen	.49	.45	.34	.03	1.31	1.34	2.65	49.4	6.20
Original soil 1929	.55	.36	.41	.03	1.35	1.37	2.72	49.6	5.51

TABLE 20. BASE EXCHANGE DATA, SUBSTRATUM SAMPLES (C), LYSIMETER SERIES B, SAMPLED APRIL, 1940, AFTER 11 YEARS IN LYSIMETERS.
(Results in mgm. equivalent per 100 gms. soil.)

Nitrogen treatment (10 years)	Exchangeable bases					Exchangeable H	Base exchange capacity	Relative base saturation %	Final pH
	Ca	Mg	K	Na	Total				
Nitrate of soda	.51	.08	.18	.31	1.08	1.09	2.17	49.8	7.63
Nitrate of potash	.40	.10	.64	.03	1.17	1.01	2.18	53.7	6.87
Nitrate of lime	.77	.05	.21	.02	1.05	1.03	2.08	50.5	6.47
Sulfate of ammonia	.14	.18	.09	.04	.45	1.97	2.42	18.6	4.66
Ammophos	.19	.22	.12	.03	.56	1.86	2.06	27.2	5.18
Urea	.50	.33	.25	.02	1.10	0.90	2.00	55.0	5.83
Calurea	.55	.45	.20	.02	1.22	0.88	2.10	58.1	6.14
Cyanamid	.46	.23	.12	.02	.83	1.10	1.93	43.0	5.63
Cottonseed meal	.46	.50	.26	.03	1.25	0.91	2.16	57.9	5.98
Castor pomace	.51	.39	.21	.03	1.14	0.94	2.08	54.8	6.06
Linseed meal	.43	.35	.25	.03	1.06	1.02	2.08	50.9	5.75
Fish meal	.51	.38	.22	.01	1.12	0.86	1.98	56.6	5.79
Dried blood	.44	.33	.27	.01	1.05	1.09	2.14	49.1	5.82
Tankage	.49	.34	.22	.02	1.07	1.07	2.14	50.0	5.85
Manure (limed)	.50	.44	.24	.03	1.21	0.85	2.06	58.7	5.88
No nitrogen	.42	.26	.34	.04	1.06	0.87	1.93	54.9	6.17
Original soil, 1929	.45	.25	.28	.02	1.00	0.95	1.95	51.3	5.48

change capacity, a small error in one or another of the determinations of individual exchangeable bases could appreciably change the apparent relative base saturation.

The total base exchange capacities, given in Tables 18, 19 and 20, represent averages between the value, as determined by ammonia replacement in the method of Pierre and Scarseth, and the total, as determined by adding the total of the individual bases to the exchangeable hydrogen as determined by barium replacement. Conversely, exchangeable hydrogen represents the average between that measured directly and that obtained by difference. The separate data from the two standpoints were in fair agreement. However, it is reasonable to expect that a more accurate picture is presented by combining them, as indicated above.

The apparent base exchange capacity of the surface soil, thus computed, appears to be increased to some extent by ammophos, cyanamid or manure. The other values are reasonably close, in all cases. The differences in organic matter content at the end of the experiment, previously given in Table 8, are not reflected in the total base exchange capacity measurements, except in the case of manure.

Evaluating Acid or Basic Effects of Fertilizers

At present, the equivalent acidity or basicity of fertilizers is usually estimated from tables based on the data of Pierre (16). These are developed from an assumption that under cropped conditions one-half of the nitrogen exerts an acid effect corresponding to its equivalent in nitric acid, and that the "ash" constituents exert net effects corresponding to the balance between their basic and acidic components. The following materials, used in this experiment to provide phosphorus, potash and magnesia, tended toward increased basicity: precipitated bone, carbonate of potash and carbonate of magnesia. Sulfate of potash (supplying one half of the potash) should be neutral in its effects. Since some of the nitrogenous fertilizers supplied other of the conventional "plant food" constituents, the amounts of the supplemental materials were not the same in all cases.

The computed acidity or basicity from the nitrogenous materials and from other sources, using Pierre's procedure, are shown in Table 21. These represent the totals of all treatments during the 11 year period.

The actual effects of the treatments upon the soil can be evaluated from two standpoints: in terms of net gain or loss in exchangeable bases and in terms of decrease or increase in exchangeable hydrogen. Since these are inter-dependent, except when there is some change in base exchange capacity, a combination of the two computations should provide a fair picture of the net soil effects with respect to soil acidity. All three of the soil layers must be combined in order to show the full action of the treatment.

Another means of measurement of the net effects of the treatment,

TABLE 21. COMPUTED EQUIVALENT ACIDITY OR BASICITY OF ALL FERTILIZER TREATMENTS, APPLIED FROM 1929 TO 1939, INCLUSIVE, WINDSOR LYSIMETER SERIES B. (Expressed as calcium carbonate equivalent, per acre.) B—basic, A—acid.

Nitrogen source	Nitrogenous material	Other materials	Net total
Nitrate of soda	3600 B	3145 B	6745 B
Nitrate of potash	3600 B	2025 B	5625 B
Nitrate of lime	2700 B	3145 B	5845 B
Sulfate of ammonia	10,700 A	3145 B	7555 A
Ammophos	10,700 A	2565 B	8135 A
Urea	3600 A	3145 B	455 A
Calurea	2340 A	3145 B	805 B
Cyanamid	5700 B	3145 B	8845 B
Cottonseed meal	2900 A	1731 B	1169 A
Castor pomace	1800 A	1530 B	270 A
Linseed meal	2980 A	1905 B	1075 A
Fish meal	1800 A	2125 B	325 B
Dried blood	3500 A	2973 B	527 A
Tankage	3000 A	2565 B	435 A
Manure	8500 B	295 B	8795 B
No nitrogen	——	3145 B	3145 B

from the standpoint of base depletion or accumulation is provided by the lysimeter data on drainage water losses and by the crop removal data, in relation to the amounts added to the soil. The bases most directly concerned are calcium, magnesium, potassium and sodium. However, since acid reacting fertilizers cause significant removals of manganese and aluminum from the soil through leaching or in the crop, it may also be considered that these represent base depletion by the treatment. Table 22 shows the results of the above schemes for

TABLE 22. EVALUATION OF NET CHANGES IN BASE STATUS OF SOIL DURING LYSIMETER EXPERIMENT B, 1929-'39 INCLUSIVE, COMPUTED AS CALCIUM CARBONATE EQUIVALENT. (In pounds per acre.) B—more basic, A—more acid.

Nitrogen treatment	From base exchange data		From lysimeter data[1]	
	Surface soil only	All three soil layers	Not including Mn and Al	Including Mn and Al
Nitrate of soda	1363 B	1636 B	1541 B	1538 B
Nitrate of potash	811 B	1207 B	2104 B	2100 B
Nitrate of lime	1110 B	1232 B	3039 B	3034 B
Sulfate of ammonia	2101 A	3624 A	3055 A	3391 A
Ammophos	2248 A	3743 A	2936 A	2989 A
Urea	937 A	1095 A	1320 A	1347 A
Calurea	1024 A	971 A	552 A	573 A
Cyanamid	3145 B	3879 B	8239 A	8234 A
Cottonseed meal	1673 A	1741 A	1909 A	1930 A
Castor pomace	1765 A	1846 A	1704 A	1727 A
Linseed meal	1840 A	1872 A	1731 A	1754 A
Fish meal	1466 A	1469 A	353 B	321 B
Dried blood	1696 A	2000 A	2149 A	2187 A
Tankage	1432 A	1743 A	240 A	261 A
Manure (incl. lime)	3432 B	3779 B	9721 B	9718 B
No nitrogen	449 B	491 B	1954 B	1952 B

[1] Representing net gains or losses due to both crop removal and leaching.

evaluating soil changes, from the standpoint of the acid or basic effects of the treatments.

The influences of treatment upon the soil are most reflected in the changes in the surface soil layer. However, in some instances, an appreciable effect is also exerted upon the subsoil or substratum, or both, as previously discussed. Lysimeter data indicates net changes of similar magnitude, when the fertilizers have tended to increase the acidity. Fish meal is the only treatment which has made the soil more acid, when the lysimeter data would indicate a slight basic effect.

Those treatments that have supplied much calcium, such as nitrate of lime, cyanamid and manure (containing some limestone), have influenced the exchangeable base status of the soil to a much lesser degree than would be indicated by the net accumulation of bases, chiefly calcium, as computed from the lysimeter "balance sheet." It is apparent that much of the calcium thus added to the soil is not accounted for in the base exchange relationships of the soil, under the conditions of this experiment.

In comparing these data with the estimates shown in Table 21, it is apparent that the quantitative effects of the treatments in most cases are quite different from those predicted on the basis of Pierre's methods of computation. The lysimeter data on basic fertilizers supplying much calcium tend to follow the estimates. Some of the organic materials show fair agreement, either from the base exchange or "lysimeter net change" standpoint. On the other hand, the soil effects of treatments including the nitrate materials and the ammonia salts have been much less basic and much less acid, respectively, in any method of evaluation, than predicted from the Pierre computation.

The failure of nitrogenous fertilizers to develop their full theoretical acid or basic effects under acid soil conditions has been discussed by the senior author in a previous publication. Briefly stated, the following factors tend to modify the results actually obtained in practice:

1. All of the nitrogen in the material is not transformed to nitrates, unless the nitrogen is supplied as nitrate salts.
2. Under acid soil conditions, nitrates, sulfates and other acidic constituents combine with aluminum, manganese, iron and perhaps other cations that may not be directly derived from base exchange complex. Thus they leach, or are removed by the crop, without corresponding depletion of the important exchangeable bases (calcium, magnesium, potassium and sodium).
3. Some nitrogen is leached from sandy soils as ammonium salts. This nitrogen fails to accomplish base depletion

of the soil, and permits acidic constituents to leach without affecting the soil bases.

4. Some nitrogen is assimilated by the crop as ammonium ions.

5. Basic constituents may accumulate in the soil in non-exchangeable form. Conversely, basic constituents may be liberated directly from the mineral components of the soil, permitting losses of soil bases by leaching or crop removal, without corresponding depletion of the bases absorbed in exchangeable form.

6. The chemical analyses of the tobacco crops harvested in this experiment do not indicate that any appreciable amount of nitrogen is thus removed from the soil without corresponding amounts of bases. (This will be discussed in the following section.) Thus nitrate withdrawn by the crop is practically as effective in base depletion of the soil as nitrate leached by drainage water.

Unfortunately, this experiment does not permit the direct evaluation of the effects of nitrogenous fertilizers alone, since other materials, tending toward increasing the base status of the soil, were added to produce a "complete" fertilizer mixture. However, one may make a reasonable estimate by correcting for the effects of the "no nitrogen" treatments, when the same amounts of other materials were used, and by proportional correction where less than normal application of the basic materials (precipitated bone, carbonate of potash and carbonate of magnesia) were employed. A limitation of this procedure is the failure to recognize differences in amounts of soil-derived

TABLE 23. ESTIMATED EQUIVALENT ACIDITY OR BASICITY OF NITROGENOUS FERTILIZER MATERIALS, AS DETERMINED IN WINDSOR LYSIMETER EXPERIMENT B.

(Expressed as calcium carbonate equivalent, per unit of nitrogen[1] in pounds per acre. Corrected for effects of other materials.)

A — acid, B — basic.

Treatment	Computed from base exchange data	Computed from lysimeter data	Average	Pierre values
Nitrate of soda	11.4 B	4.1 A	3.7 B	36.0 B
Nitrate of potash	8.9 B	8.4 B	8.7 B	36.0 B
Nitrate of lime	7.4 B	10.8 B	9.1 B	27.0 B
Sulfate of ammonia	41.2 A	53.4 A	47.3 A	107.0 B
Ammophos	41.4 A	45.8 A	43.6 A	107.0 B
Urea	15.9 A	33.0 A	24.4 A	36.0 A
Calurea	14.6 A	25.3 A	19.9 A	23.4 A
Cyanamid	33.9 B	62.8 B	53.9 B	57.0 B
Cottonseed meal	20.1 A	30.0 A	25.1 A	29.0 A
Castor pomace	20.9 A	26.8 A	23.8 A	18.0 A
Linseed meal	21.7 A	29.4 A	25.5 A	29.8 A
Fish meal	18.0 A	10.0 A	14.0 A	18.0 A
Dried blood	24.6 A	40.3 A	32.5 A	35.0 A
Tankage	21.4 A	18.5 A	20.0 A	30.0 A

[1] 20 pounds, or equivalent to 1 percent per ton.

nitrates that may be produced in the various instances. However, it will serve to give a direct comparison between the various nitrogenous materials, from the standpoint of their acid or basic effects upon the soil. The results of these computations, both on the bases of soil data for the entire profile (all three layers) and as computed from the lysimeter data, are shown as Table 23. These are calculated in terms of calcium carbonate equivalent, per unit of nitrogen (20 pounds), for convenient comparison with the Pierre values.

Estimates of equivalent acidity or basicity of fertilizer materials, as computed by Pierre's method, do not exactly account for the amounts of basic and acidic elements added to the soil in the fertilizer mixtures and in the rainfall, as shown in Table 2. Using this data, their theoretical effects may be calculated. Assuming all of the nitrogen as potentially acid, the following corrections can then be applied:

1. Nitrogen recovered in crop and leaching, in excess of addition, represents additional potential acidity. When the recovery is incomplete, the difference signifies diminished acid effects.

2. Nitrogen leached as ammonia counteracts the effects upon the soil of an equivalent amount of acid, and must also be deducted from the total nitrogen recovery.

Table 24. Computations of Acidic and Basic Effects of Treatments Based on Amounts of Various Constituents Added to Soil,[1] with Corrections for Incomplete or Excess Nitrogen Recovery in Crop and Leaching. Nitrogen Leached as Ammonia and Lack of Balance of Basic and Acidic Constituents in the Crop. Windsor Lysimeter Experiment B, 1929-'39, Inclusive.

(Expressed as $CaCO_3$ equivalent, in pounds per acre.)

A — acid, B — basic.

Nitrogen source	Computed from constituents added to soil	Correction from nitrogen recovery data	Correction from ammonia leaching	Correction from crop unbalance data	Net theoretical basicity or acidity
Nitrate of soda	2322 B	264 A	69 B	644 B	2774 B
Nitrate of potash	1961 B	243 A	61 B	342 B	2121 B
Nitrate of lime	2379 B	254 A	43 B	346 B	2514 B
Sulfate of ammonia	11,043 A	747 A	224 B	1143 B	8929 A
Ammophos	9821 A	675 B	57 B	1470 B	7619 A
Urea	3922 A	1300 B	29 B	613 B	1980 A
Calurea	2493 A	582 B	39 B	705 B	1167 A
Cyanamid	5572 B	1472 B	59 B	578 B	7681 B
Cottonseed meal	4771 A	1915 B	43 B	478 B	2335 A
Castor pomace	4175 A	1622 B	45 B	606 B	1902 A
Linseed meal	4349 A	1704 B	39 B	577 B	2029 A
Fish meal	2901 A	1729 B	40 B	408 B	724 A
Dried blood	4825 A	1307 B	29 B	686 B	2803 A
Tankage	2720 A	1400 B	39 B	390 B	891 A
Manure (with lime)	6180 B	3036 B	40 B	222 A	9034 B
No nitrogen	3213 B	1722 A	36 B	85 A	1442 B

[1] Computed from Table 2.

3. The lack of balance between basic and acidic constituents in the crop diminishes the acid effect of the nitrogen, when acidic constituents are in excess, or vice versa. (Thus, Pierre assumes that one-half of the nitrogen in the treatment is thus involved.)

This scheme of evaluation has been employed, with results as shown in Table 24.

The net theoretical effects of the treatments from this standpoint are in general agreement with the lysimeter data on net gains or losses in bases shown in Table 22, except with respect to the very strongly acid sulfate of ammonia and ammophos treatments. It seems apparent that, after the soil has been greatly depleted of bases by these materials, additional amounts of the acid-forming fertilizer cannot exert their normal effects in diminishing the base status of the soil.

Acid-Base Balance in Tobacco Crops

The data on the average composition of the crops harvested during the years when nitrogen treatments were applied (1930-'38), previously shown in Table 5, may be used to compute the acid-base balance in the crop. The ion equivalent per million of dry weight is a unit of convenient magnitude to show this relationship. When the acidic constituents (anions), assuming all nitrogen taken up as the nitrate, were found to be in excess of the basic constituents, one-half of the difference was deducted from the nitrate and entered in the table as the ammonium ion. When the basic constituents were in excess, as in two cases, the difference was assumed as undetermined or insufficiently measured anions. The results of these computations of acid-base balance in the tobacco crops are shown as Table 25.

TABLE 25. ACID-BASE BALANCE IN TOBACCO, COMPUTED FROM WEIGHTED AVERAGE COMPOSITION OF NINE CROPS GROWN IN WINDSOR LYSIMETER EXPERIMENT B, 1930-'38. (Based on dry weight, not including roots.)

Treatment	Ion equivalents, in parts per million											Total balanced equivalents
	Cations						Anions					
	K	Ca	Mg	Na	Mn	NH_4	NO_3	SO_4	H_2PO_4	Cl	Undet.	
Nitrate of soda	701	509	328	265	2	207	1778	93	74	67	—	2012
Nitrate of potash	1055	409	308	74	2	98	1717	76	58	95	—	1946
Nitrate of lime	669	845	291	29	3	101	1700	98	65	73	—	1938
Sulfate of ammonia	668	509	303	38	27	607	1614	353	88	97	—	2152
Ammophos	573	424	357	23	32	543	1535	198	128	91	—	1952
Urea	653	624	346	31	18	176	1587	112	67	82	—	1848
Calurea	663	694	330	25	13	180	1642	113	67	83	—	1905
Cyanamid	678	744	222	28	3	184	1579	138	60	82	—	1859
Cottonseed meal	625	459	372	27	13	132	1367	127	60	74	—	1628
Castor pomace	604	534	308	27	14	150	1370	109	58	100	—	1637
Linseed meal	625	509	328	28	14	137	1376	124	63	78	—	1641
Fish meal	586	634	289	28	12	110	1361	126	67	105	—	1659
Dried blood	576	534	307	28	23	158	1348	115	51	112	—	1626
Tankage	617	629	301	29	11	98	1387	119	68	111	—	1685
Manure (limed)	553	499	322	28	2	—	1021	127	73	112	71	1404
No nitrogen	571	404	252	34	3	—	835	191	84	100	54	1264

It is evident that most of the nitrate nitrogen is taken up with equivalent amounts of base (excluding ammonia) in all cases. However, there is definite evidence that there are significant withdrawals of ammonia nitrogen by the crop when nitrogen is applied directly in this form. In other instances the lack of balance, assuming all of the nitrogen to be taken up as nitrate, fails to give convincing proof of ammonia utilization by the crop. However, it is notable that the two treatments that have failed to properly meet the needs of the crop for normal growth (manure and no nitrogen) both show an apparent excess of basic constituents.

These data give a strikingly different picture from that given by the computations of Allison (1) from various analyses of other crops. They also fail to confirm the estimate of Pierre that one-half of the applied nitrogen is taken up by the crop without removing equivalent amounts of bases, in so far as the tobacco crop is concerned. They further substantiate the preliminary findings of the senior author (14), reported in a previous publication.

CONSTITUENTS LEACHED AND REMOVED BY CROP IN RELATION TO SEASONAL DISTRIBUTION OF LEACHING

As indicated in a previous section of this bulletin, intensive leaching during the growing season occurred in only one year, 1938, when the rainfall was so heavy during the growing season that all crops suffered severely from nitrogen depletion, regardless of the nitrogen source. On the other hand, in one season, 1933, the yields were so diminished by insufficient rainfall as to cause abnormally low crop withdrawals of nitrogen. The season of 1930 was also dry. The data for that year was somewhat abnormal, due to the residual effects of the 1929 crop, returned to the soil after severe hail damage. In the other six years, the crop yields were normal, and their nitrogen withdrawals were of consistent magnitude. In three of these years, 1931-'32, 1935-'36 and 1936-'37, leachings during the fall, up to the end of November, were not sufficient to fully deplete the nitrate nitrogen from the soil, as shown by the leachings resulting from heavier winter and spring precipitation. Lysimeter data for these years, in comparison with the other three years (1932-'33, 1934-'35 and 1937-'38) when nitrates were exhaustively leached during the first six-months period, serve to show the extent to which nitrate nitrogen is related to the removals of other constituents from the soil. These comparisons are presented in Tables 26 and 27. Treatments showing no consistent differences, as compared with similar materials included, have been omitted.

It is to be noted that the nitrogen leachings (as nitrate) following the summers of more abundant precipitation were uniformly smaller. No appreciable amounts of ammonia from any treatment appeared in the drainage water during the six years under consideration in this comparison. (Ammonia leachings of considerable magnitude from the sulfate of ammonia treatment were observed follow-

TABLE 26. ACIDIC CONSTITUENTS REMOVED BY LEACHING AND CROP, IN YEARS WITH LOW (l) AND HIGH (h) VOLUMES OF LEACHING DURING THE FIRST SIX-MONTHS PERIOD (1). VOLUMES OF LEACHING DURING THE SECOND SIX-MONTHS PERIOD (2) ABUNDANT IN BOTH CASES.

(Yearly average of three-year groups, in pounds per acre.)

Treatment	Nitrogen		Sulfur		Bicarbonate		Phosphorus	
	(l)	(h)	(l)	(h)	(l)	(h)	(l)	(h)
Nitrate of soda								
Leached — 1	63.3	89.0	23.0	62.0	25.3	117.1	—	0.5
Leached — 2	53.6	7.3	45.7	14.0	171.7	112.3	—	—
Crop	105.3	100.7	6.0	5.6	—	—	8.6	8.1
Total	**222.2**	**197.0**	**74.7**	**81.6**	**197.0**	**230.0**	**8.6**	**8.6**
Nitrate of potash								
Leached — 1	53.7	64.3	8.0	21.3	20.0	69.0	—	—
Leached — 2	58.3	9.0	32.0	14.3	100.0	69.3	—	—
Crop	99.3	108.3	4.3	4.7	—	—	7.5	8.6
Total	**211.3**	**181.6**	**44.3**	**40.3**	**120.0**	**138.3**	**7.5**	**8.6**
Nitrate of lime								
Leached — 1	44.0	62.7	14.0	40.0	17.0	49.0	—	—
Leached — 2	56.7	9.0	53.7	23.7	63.0	43.3	—	—
Crop	101.0	110.3	6.3	8.3	—	—	7.8	8.8
Total	**201.7**	**182.0**	**74.0**	**72.0**	**80.0**	**92.3**	**7.8**	**8.8**
Sulfate of ammonia								
Leached — 1	43.3	91.3	36.7	124.6	13.3	33.0	—	—
Leached — 2	73.7	7.3	197.0	91.0	22.7	20.0	—	—
Crop	65.3	69.7	11.0	17.7	—	—	5.0	5.3
Total	**182.3**	**168.3**	**244.7**	**233.3**	**36.0**	**53.0**	**5.0**	**5.3**
Ammophos								
Leached — 1	28.7	67.7	22.0	57.0	17.7	55.0	—	—
Leached — 2	75.3	14.7	82.0	42.0	62.3	36.0	—	—
Crop	80.7	86.7	9.7	12.0	—	—	10.9	10.7
Total	**184.7**	**169.1**	**113.7**	**111.0**	**80.0**	**91.0**	**10.9**	**10.7**
Urea								
Leached — 1	30.7	35.0	12.3	36.7	19.0	54.0	—	—
Leached — 2	48.0	7.3	53.0	27.7	51.3	41.7	—	—
Crop	91.3	92.3	6.3	7.3	—	—	7.8	7.1
Total	**170.0**	**134.6**	**71.6**	**71.7**	**70.3**	**95.7**	**7.8**	**7.1**
Cyanamid								
Leached — 1	19.3	56.3	13.3	32.0	22.3	48.0	—	—
Leached — 2	57.0	11.0	54.0	27.7	69.0	48.7	—	—
Crop	90.7	88.7	6.3	9.7	—	—	6.6	6.5
Total	**167.0**	**156.0**	**73.6**	**69.4**	**91.3**	**96.7**	**6.6**	**6.5**
Cottonseed meal								
Leached — 1	23.3	39.7	13.7	32.3	24.7	59.0	—	—
Leached — 2	46.3	9.7	45.7	24.0	65.0	43.0	—	—
Crop	81.7	80.7	7.3	9.3	—	—	7.0	6.9
Total	**151.3**	**130.1**	**66.7**	**65.6**	**89.7**	**102.0**	**7.0**	**6.9**
Castor pomace								
Leached — 1	26.7	47.0	13.3	33.0	25.3	57.7	—	—
Leached — 2	45.7	10.0	46.0	25.7	61.0	44.7	—	—
Crop	83.3	79.7	6.0	8.3	—	—	6.5	6.9
Total	**155.7**	**136.7**	**65.3**	**67.0**	**86.3**	**102.4**	**6.5**	**6.9**
No nitrogen								
Leached — 1	7.0	15.0	15.7	39.0	23.3	58.7	—	—
Leached — 2	22.0	4.7	56.0	22.3	78.7	41.7	—	—
Crop	22.3	19.3	5.0	5.7	—	—	4.2	5.0
Total	**51.3**	**39.0**	**76.7**	**67.0**	**102.0**	**100.4**	**4.2**	**5.0**

Table 27. Basic Constituents Removed by Leaching and Crop, in Years with Low (l) and High (h) Volumes of Leaching During the First Six-months Period (1). Volumes of Leaching During the Second Six-months Period (2) Abundant in Both Cases.

(Yearly averages of three-year groups, in pounds per acre.)

Treatment	Calcium		Magnesium		Potassium		Sodium	
	(l)	(h)	(l)	(h)	(l)	(h)	(l)	(h)
Nitrate of soda								
Leached — 1	15.0	24.0	2.7	5.3	15.7	30.7	82.7	183.0
Leached — 2	26.3	12.7	8.3	2.3	24.3	11.7	155.0	52.3
Crop	37.0	37.3	14.3	15.3	97.0	98.7	17.0	28.0
Total	**78.3**	**74.0**	**25.3**	**22.9**	**137.0**	**141.1**	**254.7**	**263.3**
Nitrate of potash								
Leached — 1	23.0	33.3	5.7	8.0	82.7	141.0	5.3	8.0
Leached — 2	58.7	16.7	12.0	3.0	153.3	69.7	7.7	4.3
Crop	28.3	35.3	15.0	15.3	156.3	176.3	5.0	7.3
Total	**110.0**	**85.3**	**32.7**	**26.3**	**392.3**	**387.0**	**18.0**	**19.6**
Nitrate of lime								
Leached — 1	56.7	97.3	6.3	7.3	22.3	48.3	3.7	6.0
Leached — 2	107.3	42.3	11.7	6.7	45.0	23.3	6.3	3.0
Crop	61.7	86.0	14.0	16.0	94.0	108.3	2.3	3.0
Total	**225.7**	**225.6**	**32.0**	**30.0**	**161.3**	**179.9**	**12.3**	**12.0**
Sulfate of ammonia								
Leached — 1	35.7	115.3	8.0	19.7	44.6	126.3	5.0	9.3
Leached — 2	128.7	45.7	19.7	5.7	119.0	52.7	9.7	4.0
Crop	22.7	21.0	8.3	10.0	51.3	61.7	2.0	2.0
Total	**187.1**	**182.0**	**36.0**	**35.4**	**214.9**	**240.7**	**16.7**	**15.3**
Ammophos								
Leached — 1	29.3	68.3	8.0	16.7	37.3	86.3	5.3	13.3
Leached — 2	91.7	37.7	28.0	7.6	84.0	41.3	13.0	5.0
Crop	30.3	22.0	13.0	14.0	60.7	65.0	1.7	2.0
Total	**151.3**	**128.0**	**49.0**	**38.3**	**182.0**	**192.6**	**20.0**	**20.3**
Urea								
Leached — 1	33.3	50.0	5.0	8.0	31.3	59.7	4.3	6.7
Leached — 2	75.3	30.7	13.7	4.0	64.0	34.0	7.0	3.7
Crop	46.0	48.7	12.7	18.3	88.3	98.0	3.0	3.0
Total	**154.3**	**129.4**	**31.4**	**30.3**	**183.6**	**191.7**	**14.3**	**13.4**
Cyanamid								
Leached — 1	26.6	36.3	2.3	6.4	25.7	62.3	3.3	7.0
Leached — 2	97.3	42.3	13.0	3.3	64.3	32.0	5.7	2.7
Crop	60.0	51.0	7.3	9.0	93.0	97.0	2.7	2.0
Total	**183.9**	**129.6**	**22.6**	**18.7**	**183.0**	**191.3**	**11.7**	**13.4**
Cottonseed meal								
Leached — 1	25.6	47.7	4.3	10.0	33.0	71.3	4.3	7.0
Leached — 2	64.7	29.3	16.7	4.3	66.7	36.0	6.7	3.7
Crop	34.7	39.0	19.7	19.0	87.3	100.0	2.3	2.7
Total	**125.0**	**116.0**	**40.7**	**33.3**	**187.0**	**207.3**	**13.3**	**13.3**
Castor pomace								
Leached — 1	29.0	49.3	5.0	10.3	35.3	77.0	4.7	7.3
Leached — 2	69.0	31.7	14.3	3.7	66.3	36.7	7.0	3.3
Crop	38.7	43.3	15.3	15.0	82.7	93.0	2.7	3.0
Total	**136.7**	**124.3**	**34.6**	**29.0**	**184.3**	**206.7**	**14.4**	**13.6**
No nitrogen								
Leached — 1	14.0	33.0	2.7	5.3	25.0	59.3	2.3	5.7
Leached — 2	48.3	17.3	9.3	3.0	64.7	27.3	5.7	2.7
Crop	12.7	15.0	5.3	5.3	32.0	43.0	1.0	2.0
Total	**75.0**	**65.3**	**17.3**	**13.6**	**121.7**	**129.6**	**9.0**	**10.4**

ing the extremely heavy midsummer rains of 1938.) It is difficult to account for the consistently diminished nitrogen recovery in the years with greater summer rainfall. However, two possibilities seem most logical. Micro-biological activities are more active in soils that do not become too dry during the warmer months. Thus more nitrogen is temporarily tied up in microbial protoplasm. Also, somewhat warmer, less excessively wet soil conditions prevailed during the fall months in the years with greater nitrogen liberation. Nitrogen in the root residues of the crops was thus more likely to have been liberated by the organisms effecting their decay. However, nitrogen recoveries under the various treatments were proportionally similar in both groups of years, except for urea, which gave unusually low leachings in the years marked by wetter summers. Smaller proportions of the nitrogen were accounted for in the leachings from the nitrate treatments during the second period, especially in the "dry summer" years. However, in both cases, the crops obtained more nitrogen from these materials.

Sulfur was lost by leaching in greater relative proportions than nitrogen during the second six-months period. Even in the wetter years, the later sulfate leachings were considerable. Bicarbonates also persisted in the drainage water during the second period, after nitrate had been greatly depleted. Interesting differences in bicarbonates in the drainage water were observed between the various treatments. Unusually high amounts under nitrate of soda, and low quantities under sulfate of ammonia, are noted.

Phosphorus, not leached to a measureable degree except under nitrate of soda in wet seasons, was removed by the crop in general proportion to the yield, with no consistent relation to seasonal leaching.

Of the basic constituents, calcium was usually higher in the crop in the wetter seasons, except for strongly acid sulfate of ammonia and ammophos treatments. Here, in spite of lower nitrogen intake in the drier summers, more calcium was removed by the crop. However, in general, less calcium was removed by the drainage water in the years of more abundant early leaching, thus giving generally less total calcium losses. Nitrate of lime and cyanamid, supplying similar amounts of calcium, provide marked contrasts in calcium leachings and crop withdrawals. Drainage losses were much greater under the former treatment. Cyanamid materially affected the calcium in the crop, but did not produce more in the drainage water than other treatments supplying no unusual amounts of this constituent. This is to be expected when it is considered that nitrates are the chief factor in calcium depletion by leaching.

Crop removals of potassium represent much larger proportions of total losses than those of calcium. It is also noted that potassium persists to a greater degree in the second period of the wetter years. Hence losses of this element are greater in years when there are greater volumes of leaching.

Magnesium leachings in relation to the distribution of drainage water collections tend to run parallel to those of calcium. However, magnesium is generally higher in the crop in the wetter seasons, in opposition to the trends for calcium and potassium. Crop removal of magnesium constitutes a large share of the total magnesium loss.

Sodium losses by leaching are in general relation to the distribution of leaching volume, by periods. However, except in case of the nitrate of soda treatment, the amounts involved are too small for adequate comparison.

The tables do not include available data on chlorides, manganese and aluminum. Chlorides leached similarly to nitrates. However, since substantial increment continue to enter the soil by atmospheric precipitation throughout the year, the later periods tend to yield sustained chloride leachings. Manganese was not leached to a measurable extent, except under the two most acid nitrogen treatments. However, liberation of manganese by the soil under other treatments is revealed by the manganese in the crop, in general relation to the acid or base tendency of the fertilizer (see Table 23). Aluminum was not determined in the crop. It was a constituent of drainage water under the sulfate of ammonia treatment in the later years of the experiment.

Ammonia nitrogen leachings were inconsequential, usually not more than a pound per acre per year, except as a result of the wet summer of 1937 and the extremely heavy July rainfall of 1938, when June nitrification was presumably more complete than under sulfate of ammonia, leaving no ammonia residue to be leached in the following month.

The effects of seasonal conditions on the actual composition of the tobacco crop is best shown by expressing the various constituents on an equivalent basis., as shown in Table 28. These data represent the weighted averages of the crops grown during the three years of prevailing low rainfall (l) and the three years of abundant rainfall (h) during the growing season, discussed in the preceding paragraphs.

The nitrogen in the crop has been apportioned between nitrates and ammonia, as required, in order to adjust the acid-base balance. The apparent intake of nitrate nitrogen per unit of dry weight production is similar in both wet and dry years, and is in general relationship to the nitrate supply in the soil during the growing period. Leaching from the root zone was not sufficient to limit nitrate assimilation to a material degree, in years under consideration. However, in the wetter years the rate of nitrate intake was usually somewhat less. The larger crops in the wetter seasons usually more than offset this difference, as previously shown in Table 26.

In most instances apparent ammonia absorption was greater in the drier years. However, the reverse is true for those treatments that were most likely to provide considerable amounts of ammonia

TABLE 28. ACID-BASE BALANCE OF VARIOUS CONSTITUENTS IN TOBACCO CROPS GROWN IN THREE DRY SEASONS (1) AND THREE SEASONS OF ABUNDANT RAINFALL (h).
(Ion equivalents, in parts per million)

Treatment	Average dry weight of crop (Lbs. per A.)	Cations						Anions				Undet.	Total balanced equivalents
		K	Ca	Mg	Na	Mn	NH_4	NO_3	SO_4	H_2PO_4	Cl		
Nitrate of soda													
(1)	3708	670	499	317	201	2	293	1753	100	75	54	—	1982
(h)	3648	694	509	344	336	2	162	1812	96	71	68	—	2047
Nitrate of potash													
(1)	3597	1114	394	343	61	3	136	1835	75	68	73	—	2051
(h)	4278	1055	414	294	75	2	86	1719	69	65	73	—	1926
Nitrate of lime													
(1)	3856	625	798	298	26	4	173	1698	102	65	59	—	1924
(h)	4596	604	933	286	28	3	51	1663	113	61	68	—	1905
Sulfate of ammonia													
(1)	2100	625	537	325	42	30	567	1653	327	78	68	—	2126
(h)	2195	717	479	374	40	25	647	1622	503	78	79	—	2282
Ammophos													
(1)	2880	540	527	371	26	33	452	1551	210	123	65	—	1949
(h)	2912	594	379	395	30	35	563	1566	257	119	54	—	1996
Urea													
(1)	3427	658	669	305	39	22	233	1667	114	74	71	—	1926
(h)	3956	635	614	381	33	15	112	1552	115	58	65	—	1790
Cyanamid													
(1)	3825	622	783	157	31	4	161	1505	130	55	68	—	1758
(h)	3373	737	753	219	26	3	232	1719	108	61	82	—	1970
Cottonseed meal													
(1)	3740	596	464	433	27	15	136	1418	122	61	70	—	1671
(h)	3947	648	494	395	30	13	83	1382	147	58	76	—	1663
Castor pomace													
(1)	3564	594	544	353	33	16	185	1486	105	58	76	—	1725
(h)	3990	596	544	309	33	15	96	1332	130	55	76	—	1593
No nitrogen													
(1)	1667	492	379	261	26	3	86	872	187	81	107	—	1247
(h)	1741	632	429	250	50	4	—	794	204	94	136	137	1365

nitrogen in the soil during the growing season: sulfate of ammonia, ammophos and cyanamid.

As pointed out in the previous section, the total base intake per unit of dry weight is chiefly determined by the nitrate assimilation. However, the distribution of the bases is conditioned by their relative availability, as affected by base exchange interactions with the soil solution. An interesting example is provided by the magnesium content of the tobacco under cyanamid and cottonseed meal treatments. In the former case, the soil is so well supplied with exchangeable calcium that a high proportion of this base is taken up by the crop, thus depressing magnesium intake. On the other hand, calcium supply under the cottonseed meal treatment is lower than normal, permitting a larger removal by the crop. The reciprocal relations between the various bases are so complex that no consistent differences between intake of any single base, under the various treatments, can be ascribed to seasonal factors. Bailey and Anderson (4) have pointed out interesting differences in the chemical composition of Havana seed tobacco as affected by dry or wet season. Their data show similar discrepancies due to reciprocal effects. Potash was consistently higher in the crop in wet years in one series where the only variable was the source of potash. On the other hand, in a lime series liming appeared to accentuate a generally higher potash content in the wet year. Similar contradictions would be indicated in the present experiment, comparing the nitrate of lime and cottonseed meal, for instance.

CONCLUSIONS ON VARIOUS NITROGENOUS FERTILIZERS

The results of the several comparisons that have been discussed in the preceding pages appear to substantiate the following statements with respect to the individual characteristics of the nitrogenous fertilizer materials manifested in this study:

Nitrate of soda: Nitrogen from this material is completely available to the crop. However crop production fails to utilize much of the nitrates. The residue is quantitatively removed from the soil by leaching. Under normal rainfall conditions in Connecticut, nitrate leachings during the growing season of a midsummer crop are insufficient to produce appreciable losses of nitrates from a sandy loam of fair loaminess and organic matter content. However, the earlier removals of larger amounts of nitrates by leaching than under other treatments indicate the possibilities of depletion below an amount sufficient to properly nourish the crop, when an unusually heavy rainfall in a single storm period is experienced. In June and July, 1938, nitrogen in the drainage water represented substantially all that was supplied in the fertilizer, and the crop obtained little more nitrogen than where none was added to the soil.

Losses of calcium by leaching are at a minimum under this treatment, since nitrates and other acidic constituents in the drainage wa-

ter are chiefly combined with sodium. However, crops are less able to obtain calcium, due to the reciprocal effects of the greater intake of potassium and sodium.

A soil cropped to tobacco is made less acid by supplying nitrogen in this material, but to a lesser extent than indicated by tables in current use based on Pierre's computations.

Annual cropping to tobacco, without green manure or cover crop, causes a considerable decline in soil organic matter and some loss in soil nitrogen, when this material is the sole source of nitrogen.

Nitrate of potash: When all of the nitrogen is supplied from this source, an unnecessarily high potassium supply is provided. This extra potash has been reflected in the crop, in the leachings and in the accumulation of exchangeable potassium in the soil. Much smaller proportions of this element are leached than in case of the sodium constituent of the nitrate of soda treatment. There is an indication that nitrates are slightly less readily leached when supplied as nitrate of potash. This material also tends toward decreasing the acidity of the soil. Soil changes indicate that this is chiefly due to increased exchangeable potassium in the soil.

Nitrate of lime: Nitrates from this material are similarly distributed between crop removal and leaching, as under the other two nitrate materials. Little of the extra calcium applied in this treatment is either removed by the crop or lost in the drainage water. However, the accumulation of this constituent in the exchangeable form fails to account for nearly all of the apparent net gain to the soil. The increased calcium in the crop has had some reciprocal effect in causing small proportional amounts of the other bases, especially magnesium.

Sulfate of ammonia: This source of nitrogen has had pronounced effects upon both the soil and the crop. The acid effects have depleted the soil bases to a marked degree, chiefly through the leaching engendered by the sulfate constituent. Nitrate production in the soil is somewhat delayed, as witnessed by the lower proportionate leaching during the first three months after fertilizer application. Very heavy rains in early summer can cause considerable amounts of ammonia nitrogen to be washed through a sandy loam soil, at least to the depth of 18 inches.

Not all of the nitrogen provided as sulfate of ammonia can be accounted for in the crop, in the leaching or in determined nitrogen residues in the soil.

Tobacco crops supplied with nitrogen from this material have shown poor yields. The crop is unusually high in nitrogen, presumably due to absorption of ammonia nitrogen in addition to nitrates. The increased sulfur intake by the crop has tended to sustain the percentages of non-volatile bases. However, the greater portion of the sulfate constituent is removed in the drainage water. The acid effects

of the treatment are also evidenced by increased manganese in the crop and leaching, and by the diminished bicarbonate content of the leachate and measureable amounts of aluminum dissolved from the soil. However, the net losses of the important soil bases (calcium, magnesium, potassium and sodium) fail to show acid effects of the magnitude usually ascribed to this material. This may be due to the relatively low initial base status of the soil employed in this experiment.

Ammophos: This material, when used as the sole source of nitrogen for the tobacco crop, supplies exceptional amounts of phosphorus. However, in spite of the large application of this constituent, no losses by leaching occurred. Only a few pounds could be accounted for in the increased phosphorus intake by the crop. The remainder produced an increase in the total phosphorus of the soil.

Larger crops were obtained from this "ammonia nitrogen" source than in the case of sulfate of ammonia. However, apparent ammonia utilization by the crop and increased manganese content were also observed. The calcium content was adverserly affected, almost to the same degree as caused by the extra potassium in the nitrate of potash treatment. The base depletion of the soil caused by the combined effect of ammophos and the lessened basicity of other materials was similar in magnitude to that caused by sulfate of ammonia.

The early leachings of nitrates from this material were unusually small. However, it must be considered that the crop was withdrawing more nitrogen during this period than in the case of sulfate of ammonia, due to the adverse effect of the latter. The total liberation of nitrogen during the year was incomplete. Some residue of nitrogen remained in the soil.

Urea: The results from this material are of special interest, since it is beginning to replace natural organic nitrogen sources in fertilizer mixtures. It appears to liberate a somewhat greater proportion of its nitrogen than do the vegetable derived organics, although not significantly more than from dried blood or tankage. A substantial proportion of its nitrogen is not accounted for in the crop or the drainage water losses. This is confirmed by a gain in soil nitrogen. However, the organic matter of the soil was less sustained than when cottonseed meal or castor pomace were used as the nitrogen source.

Urea is definitely an acid-producing fertilizer, but to a much less pronounced degree than is sulfate of ammonia. The net acid effect of urea, in combination with other fertilizer constituents, was less than that shown by organic materials since these were used with smaller amounts of basic materials. The acid tendency of urea is in general agreement with current estimates by other investigations.

Calurea: This material gave promise of being an important source of nitrogen when this experiment was started in 1929. However, it has since disappeared from the American market. It is es-

sentially a mixture supplying four-fifths of its nitrogen as urea and one-fifth as nitrate of lime. The results obtained are consistent with this condition. The initial provision of some nitrate nitrogen has tended to cause earlier nitrate loss by leaching, greater nitrogen utilization by the crop and larger total nitrogen liberation during the year than when all of the nitrogen is supplied as urea. The increased calcium has also been evidenced in the crop.

Cyanamid: This material was applied to the soil four weeks earlier than other treatments, in order to avoid initial toxic effects upon crop growth. Despite this advantage, the liberation to the soil as nitrates appears to be unusually slow. The crop was able to obtain normal amounts of nitrogen, comparable in this respect to most other materials with the exception of the nitrates. Some of this nitrogen intake seems to have been in the form of ammonia.

The unusual amounts of calcium provided in this treatment are reflected to some extent in the greater proportion of calcium in the crop. The loss of this constituent by leaching has not been correspondingly affected. The net result has produced a great increase in the calcium content of the soil, sufficient to practically saturate the base exchange capacity, with a considerable net gain in the base status in excess of amounts thus measured.

Cottonseed meal: This is the organic nitrogen source most generally used for tobacco in the Connecticut Valley. It is also used as a constituent of mixed fertilizers for other crops. The amount of nitrogen applied in this experiment would be considered excessive for most crops. However, it is the common rate for tobacco in this locality.

In this experiment the crop has been able to utilize less than 40 percent of the nitrogen added in the treatment. However, since the total nitrogen liberation under cottonseed meal has been but 72.5 percent of the application, the crop actually obtained approximately 51 percent of the amount of nitrogen becoming available in the soil during the year. The percentage of nitrogen in tobacco was consistently lower than under any of the inorganic treatments, but was adequate for normal growth. In reasonably wet seasons, when some leaching of nitrates from the root zone occurred, the nitrogen obtainable by the plant was on the verge of insufficiency. The leaching of 78 pounds of nitrogen per acre produced by the excessive summer rainfall in 1938 left the soil so depleted that the crop could obtain but 45 pounds. This and other evidence leads to the conclusion that, although 200 pounds of nitrogen are applied and a small additional amount must be obtainable from the soil itself, only about 125 pounds of available nitrogen is developed in the soil during the growing season of the tobacco crop under normal fertilizer practice. Unless unusually heavy rains materially deplete the soil below this level, the crop can obtain an adequate but not excessive amount under these conditions.

The total availability of cottonseed meal is definitely less than that of urea, dried blood or tankage, and apparently slightly less than castor pomace and linseed meal. The rate of availability is similar to other high-grade organics and is not materially different from urea.

Cottonseed meal is somewhat acid in its effects upon the soil. The currently used estimate that 200 pounds of limestone would be required to counteract the acidity of a ton of cottonseed meal of average composition is supported by the results of this experiment.

Unless calcium is supplied from other sources, such as gypsum or limestone, as was not done in this experiment, a tobacco fertilizer in the "2-1-2" ratio, formulated from cottonseed meal, precipitated bone and the usual materials to supply potash and magnesia, favors a definite depletion of the available calcium supply of the soil. Magnesium is more readily available to the plant under such conditions, but the calcium intake by the crop may become critically low, especially from the standpoint of quality production.

The use of cottonseed meal as the source of nitrogen causes some increase in the residual nitrogen of the soil, and tends to maintain soil organic matter, to a significantly greater degree than when nitrogen is derived from inorganic materials. However, unless green manure or cover crops are grown, soil organic matter is not fully maintained.

Castor pomace: The results from this material have been similar to cottonseed meal. However, it appears to liberate somewhat more of its nitrogen at a slightly greater initial rate. The acidity and base relationships of castor pomace are also much like those for cottonseed meal.

Castor pomace caused an unexpectedly high residual effect upon soil organic matter. This has been repeatedly checked on several soil samples with consistent results. This could be due to the possibility that castor pomace is essentially a mixture of two types of material: one of high nitrogen content and rapid availability producing little organic residue; the other of low organic nitrogen content and high in lignin or other substance quite resistant to decay. This feature is to be studied more fully. If confirmed and explained, such a characteristic of castor pomace would be an important consideration in its use.

Linseed meal: The nitrogen availability of this material is intermediate between cottonseed meal and castor pomace. It does not exhibit the residual effect on soil organic matter noted for the latter. Its effects upon soil acidity and base inter-relationships are similar to the other vegetable-derived organics. None of the data discloses any explanation for the belief prevalent among tobacco growers that this material imparts special quality characteristics.

Fish meal: Used in this experiment as the sole source of nitrogen, this material supplied more than the normal amounts of phos-

phorus. This was very slightly reflected in the crop. However, the increased phosphorus residue in the soil was of a measureable extent. It is of interest to note that the apparent availability of this residual phosphorus appeared to be unusually high.

The nitrogen availability of fish meal is similar to cottonseed meal. A slightly larger average yield, of similar nitrogen content, resulted in a somewhat larger proportionate intake by the crop.

Since this treatment supplied more calcium than most others, the crop was improved in this respect. Calcium leachings were not increased to a material extent. Hence the base status of the soil was well conserved and little acidity was developed. Soil organic matter was apparently not as well maintained under the fish meal treatment as under the organics previously discussed.

Dried blood: This material is not now in common use in tobacco and other fertilizers, due to cost differentials. However, it is the common standard of nitrogen availability for organic fertilizer. It is slightly more fully available than other natural organic materials. Results from urea and dried blood are quite similar.

This treatment caused a material increase in soil acidity to a somewhat greater degree, from all standpoints, than produced by other organics used in this experiment.

Tankage: In common with fish meal, this material supplied more phosphorus and calcium than the normal treatments. This caused a significant effect upon the calcium content of the crop and a slight increase in the removal of phosphorus by the plant. Residual phosphorus in the soil was materially increased.

From the nitrogen standpoint, tankage performed similarly to dried blood. Generally good crop yields resulted in somewhat greater utilization of nitrogen than shown by most other organics. The effects of this material in increasing soil acidity and depleting soil bases are less pronounced than dried blood, but are apparently somewhat greater than in case of fish meal.

Manure: The manure used during most of the years of this experiment was cow manure to which some limestone had been added. This disturbing factor, overlooked until too late, is an important consideration in interpreting the results. It appears likely that most of the corrective effect that has been exerted upon soil acidity is not due to the manure itself.

As a nitrogen source, this manure was of a low order of availability, both from the standpoint of total nitrogen liberation and the rate of nitrification. This condition was reflected in the low crop yield and the much lower nitrogen content of the crop, as compared with all other treatments adding equal amounts of nitrogen. It appears that little more than half of the nitrogen in the manure was liberated during the entire period of the experiment, and that not more

than about 80 pounds of nitrogen per acre was released during the summer, an entirely adequate amount for normal tobacco growth.

The marked residual effect of manure upon both organic matter and nitrogen in the soil was fully confirmed. This residual nitrogen is in part available to subsequent crops, as attested by the fact that the tobacco crop in 1939, without nitrogen treatment, obtained practically the same amount of nitrogen as had been obtainable as an average of the nine preceding manured crops.

No nitrogen: As expected, tobacco yields were greatly diminished when nitrogen was omitted from the treatment. The nitrogen content of the crops was also unusually low. Yields tended to decline. The annual nitrogen liberation from the soil fell from a range of 56 to 80 pounds in the first three years of the experiment, to from 31 to 45 pounds in the last three years. Similar results were obtained under uncropped conditions following the discontinuance of nitrogen treatment after three years of hoof and horn meal application without subsequent cropping.

In the absence of nitrogen fertilizers, materials used to provide other fertilizer constituents tended to overcome the initial acid conditions of the soil.

Without nitrogen in the treatment, there was a decline in soil nitrogen, corresponding to nitrogen removal by crop and leaching. Approximately 5 tons of organic matter were lost to the soil in the course of the 11 years of the experiment.

SUMMARY

A comparative study has been made between 15 materials that may be used to supply nitrogen to the soil. These have been added to soils in outdoor lysimeter tanks, in addition to other materials containing no nitrogen, but supplying amounts of phosphorus, potassium and magnesium corresponding to those used in tobacco fertilization in the Connecticut Valley. The nitrogenous materials were applied in amounts supplying 200 pounds of nitrogen per year. Crops of tobacco were grown and harvested annually, except in the first year when the crop was destroyed by hail. The soil was a Merrimac sandy loam, typical of areas most extensively used for tobacco. The tanks contained 7 inches of normal surface soil, over subsoil and substratum material sufficient to make up a total depth of 18 inches. The soils in each tank were made as uniform as possible by thorough mixing of each of the three layers represented.

The experiment was conducted for ten years of nitrogen treatment and for an additional year without nitrogen to show residual effects, from May, 1929, to April, 1940. Wide variations in weather conditions were experienced between these dates. In some years, rainfall was insufficient to produce leaching until late fall or early winter. In others, cold winter kept the soil frozen from November until

late March, thus preventing percolation of water through the soil. In some years unusually heavy summer rains or thawing of the soil during the winter produced leaching more frequently and in greater volume. Each calendar month brought some drainage water through the soil in at least one of the 11 years. Soil leaching in July occurred in only two instances, and was of significant magnitude only as a result of the extremely heavy rainfall of 1938. August showed a negligible leaching in only one instance. The greatest volumes of drainage water collection were usually obtained in March, April and November. The average daily loss of moisture from the soil by evaporation and crop transpiration during the summer months was equivalent to approximately one-tenth of an inch of rainfall. In the winter period, evaporation is only slightly over one-half of the summer loss to the atmosphere.

The variations in amounts and distribution of rainfall from year to year greatly affected the occurrence of significant losses of nitrogen from the soil by leaching. The availability of nitrogen to the crop was not appreciably affected by leaching during the growing season, except under the unusual 1938 conditions. In that year the leaching in July, after most of the available nitrogen had accumulated as nitrates from all treatments, depleted the soils under all treatments to such an extent that very poor crops of low nitrogen content were obtained in all cases.

Differences in amounts and rates of available nitrogen liberation in the soil between the various treatments were revealed in the following measurements: total amounts of nitrogen removed in the crop; unit composition of the crop; nitrogen represented in the drainage water in successive periods of leaching; the residual nitrogen after ten years of treatment, as measured by crop and leaching, and nitrogen content of the soil at the termination of the experiment, in relation to the initial condition.

From the above standpoints, it is evident that the readily available nitrate materials under study (nitrate of soda, nitrate of potash and nitrate of lime), supply more nitrogen to the crop and are more completely removed from the soil by crop and leaching than any of the other materials used in the comparison. A larger percentage of nitrogen is removed from the soil by early periods of leaching than in later ones. However, since higher nitrate nitrogen levels existed in the soils prior to leaching, the depletion was not severe except in the one instance when all treatments were exhaustively leached.

The sulfate materials (sulfate of ammonia and ammophos) liberated nearly 90 percent of their nitrogen to the soil or to the drainage water. However, the marked increase in soil acidity and the development of unbalanced soil conditions adversely affected the crop, particularly in the case of sulfate of ammonia. There was good evidence that a considerable proportion of the nitrogen in the crop was taken up as ammonium ions. The rate of nitrate production from these sources appeared to be somewhat retarded. Appreciable amounts

of ammonia were leached when heavy rains occurred in early summer, as in 1937 and 1938.

Urea was somewhat less completely recovered in crop and drainage water than were the ammonium salts. However, earlier nitrate production was evidenced. Results were similar to those from natural organics. Calurea gave a somewhat higher nitrogen recovery, with earlier leaching, due to the fact that one-fifth of the nitrogen is thus supplied as the nitrate.

Cyanamid, although applied four weeks earlier than other materials, was less readily leached. Total nitrogen recovery in both crop and leaching were like those from urea.

The natural organic materials (cottonseed meal, castor pomace, linseed meal, fish meal, dried blood and tankage) gave similar results from the standpoint of nitrogen liberation and rates of nitrogen leaching. In all cases, much of the nitrogen was not recovered in either crop or drainage water, and significant gains in soil nitrogen were in evidence at the end of the experiment. However, the soil gains were not sufficient to account for the computed balance. Dried blood and tankage showed somewhat greater nitrogen availabilities than other organics. Cottonseed meal was apparently more gradually and incompletely nitrified.

It is estimated that, when 200 pounds of nitrogen per acre are added in organic materials of availability similar to cottonseed meal, approximately 125 pounds of available nitrogen per acre are provided in the soil during the growing season of the tobacco crop.

The nitrogen in manure was much less available, from all standards of measurement, than that in any of the fertilizer materials.

Without a nitrogen fertilizer, this previously well-fertilized soil liberated from 50 to 80 pounds of nitrogen per acre annually during the first three years. There was a subsequent decline to but from 30 to 35 pounds per acre yearly. Only about 40 percent of these amounts were available to the tobacco crop.

The soil that received no nitrogen during the 11-year period, showed a nitrogen loss to the soil of similar magnitude to the recovery in crop and leaching. The soil organic matter was greatly depleted, at a rate approximately one-half ton yearly. The nitrate fertilizer treatments did not appreciably check this loss in organic matter. With other inorganic nitrogen fertilizers the loss was generally about 60 percent as great as indicated above. Several of the organic nitrogen fertilizers greatly retarded the net loss in soil organic matter. Castor pomace and manure produced gains of considerable magnitude. In case of castor pomace, this may be associated with its higher contents of lignin and cellulose.

The various nitrogenous fertilizers differed greatly with respect to their effects upon the removals of various other constituents by

crop and leaching. Nitrate of soda, leaching most of the acid constituents (nitrates, sulfates, bicarbonates and chlorides) as salts of sodium, was less depleting of other bases. Nitrate of potash or nitrate of lime left considerable residues of potassium or calcium in the soil, much in readily active, or "exchangeable," form. Sulfate of ammonia and ammophos greatly depleted the sum total of exchangeable bases in the soil. Urea, calurea and all of the organic fertilizer materials, with the possible exception of fish meal, depleted the soil of one or more of the important soil bases through crop removals or leaching losses in excess of the amounts applied in the treatments, thus causing the development of acid condition through decreasing the relative base saturation of the "exchange complex."

Cyanamid and manure (contaminated with limestone) supplied such great residues of calcium that the soils under these treatments were practically saturated with bases at the end of the experiment.

Amounts of the various constituents, removed by six-months periods in the drainage water and in the harvested crops, were compared on the basis of average data for three-year groups represented by low and high volumes of summer and fall leaching. When the early leaching was high, most of the nitrates not taken up by crops were removed from the soil by November 25. Sulfate and bicarbonate depletion was less readily effected. Potassium leachings did not parallel the nitrate leachings as closely as did those of other bases. In dry summers, with rainfall during the first period insufficient to effect much depletion of soluble constituents, calcium was leached from the soil to a greater degree, especially in the later period.

Of the total amounts liberated during the year, potassium is more effectively utilized by the crop than are the other bases. However, in years of heavy precipitation, leaching losses of potassium are increased relative to crop intake.

The acid-base equilibria, represented by the various constituents removed by the tobacco crops, show a greater apparent intake, in the drier seasons of ammonia nitrogen from treatments that do not supply ammonia as such. The ammonium salts seems to yield larger proportions of ammonia to the crop in wet seasons. Characteristics of the various fertilizer materials, as revealed in this experiment, are discussed in the preceding section.

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